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NOTES ON MEDINAN, NIAGARAN, AND CHESTER FOSSILS

AUG. F. FOERSTE

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A. THE CORRELATION OF OHIO, INDIANA, AND KENTUCKY MEDINAN AND NIAGARAN STRATA

In East-Central Kentucky the following Silurian strata, in descending order, may be discriminated.¹

Crab Orchard division of Niagaran	Alger formation	<div> <div>Estill clay</div> <div>Waco limestone</div> <div>Lulbegrud clay</div> </div>
	Indian fields formation.	<div> <div>Oldham limestone</div> <div>Plum creek clay</div> </div>
Medinan	Brassfield formation	Brassfield limestone

The so-called Waco limestone is merely that part of the Alger formation in which a few limestone layers occur. In the type area one of the limestone layers is from 1 to 2 feet thick. The other limestone layers are less than 1 inch thick. Fossils occur both in the limestone and in the clay shale. Neither limestone nor fossils can be traced north of Indian Fields, Kentucky, and

¹ Foerste, A. F., The Silurian, Devonian and Irvine formations of east-central Kentucky: Kentucky Geol. Survey, Bull. 7, 1906, p. 27.

farther north the collective term Alger clay is used for the continuous clay shale section forming the upper part of the Silurian in Montgomery, Bath, and most of Fleming county. In Lewis county, and in the northern part of Fleming county, this Alger clay is overlain by the Bisher member of the Niagaran. In Lewis county the upper part of the Alger clay contains *Liocalymene clintoni* and other fossils indicating relationship with the Clinton of Maryland and the typical Clinton of central New York, as exposed in the vicinity of the village of Clinton in that state.

The Oldham limestone consists of thin limestone interbedded with thin clay shale. It contains very few fossils and of these only *Stricklandinia norwoodi* has been recorded. Since this species does not occur elsewhere than in east-central Kentucky it is of no service in correlation. The Oldham limestone may be followed lithologically as far north as the Rose Run Quarries, about 7 miles east of Owingsville. Farther north it can not be discriminated readily from the underlying Plum Creek clay shale, since the latter there also contains thin limestone layers, often in considerable quantity.

Throughout southwestern Ohio there is a series of very white and fine grained limestones known as the Dayton limestone. In Highland and Adams counties in Ohio, and in the adjacent parts of Lewis county in Kentucky, this Dayton limestone lies immediately beneath a thick clay shale zone regarded as the northward extension of the Alger clay. Since the Dayton limestone in Highland and Adams counties contains *Pentamerus oblongus*, it is regarded provisionally as corresponding to one of the so-called Clinton *Pentamerus* horizons of the more western parts of New York. Possibly it corresponds approximately to the Walcott limestone of the Clinton as exposed in the Rochester area of New York. In that case the Dayton limestone forms the base of that part of the Ohio Niagaran which corresponds to the Clinton of New York, when this term is used so as to include the Clinton of Western New York at Rochester and as far west as Niagara Falls and southern Ontario as well as the typical area around Clinton, New York.

Nothing is known of the fossils of the Plum Creek clay shale, at least within the area of its typical exposure. Farther north, at the Rose Run quarries, east of Owingsville, Kentucky, a considerable fauna once was exposed in strata overlying the iron ore horizon. This fauna never was collected but it contained species resembling *Clathropora clintonensis*, *Strophonella daytonensis*, and other species resembling forms known in the Brassfield limestone, but at the time this fauna was examined in the field it was regarded as sufficiently distinct from the typical Brassfield to be regarded as probably of Niagaran age.

The Brassfield limestone is regarded as equivalent to part of the Medinan section in the Niagara Falls area of New York and in southern Ontario.

At the base of the Brassfield limestone, in the quarry immediately north of Lawshe, in Adams county, Ohio, *Platymerella manniensis* Foerste was found in a thin horizon only a few inches thick.² This occurrence is of interest because the same species occurs at a corresponding horizon in western Illinois and eastern Missouri.³ At these western localities the *Platymerella* horizon is underlain, in descending order, by the Essex, Edgewood, and Girardeau limestones. Recently fossils have been found in argillaceous strata underlying the typical Brassfield limestone, in Montgomery county, Ohio. These beds are of Silurian age and may correspond approximately to one of the western horizons, presumably to the Edgewood limestone, as far as may be determined from the meager data secured so far. In that case they belong beneath the *Platymerella* horizon.

This lower Silurian horizon in Ohio may belong beneath the argillaceous horizon for which the name Belfast bed was proposed 27 years ago.⁴ At the time this name was proposed two Silurian species were known from the top of the Belfast bed, *Halysites catenulatus*, and a form of *Orthis flabellites* with 44

² Foerste, A. F., The Kimmswick and Plattin Limestones of Northeastern Missouri: Denison Univ. Bull. Sci. Lab., vol. 19, 1920, pp. 223, 224.

³ Savage, T. E., Stratigraphy and paleontology of the Alexandrian series in Illinois and Missouri: Ill. State Geol. Survey, Bull. 23, 1913, p. 36 of reprint.

⁴ Foerste, A. F., The Middle Silurian rocks of Ohio and Indiana: Jour. Cin. Soc. Nat. Hist., vol. 18, pp. 163-166, 1896.

radiating plications, probably identical with *Orthis dinorthis* Foerste.⁵ These fossils suggest Brassfield affinities. Recently Prof. W. H. Shideler, of Miami University, found specimens of *Whitfieldella* and other fossils having a Silurian aspect in argillaceous strata immediately beneath the typical Belfast bed on Beasley Fork southeast of West Union, Ohio. Their horizon probably is the same as that of the Montgomery county specimens provisionally referred to the Edgewood.

In Montgomery county, Ohio, the upper part of the Brassfield limestone frequently contains interbedded layers of richly fossiliferous clay. Many fossils occur here which are unknown in the underlying parts of the Brassfield limestone, though the more commonly known fossils occur at both horizons. In general, the Brassfield limestone of Ohio, Indiana, and Kentucky appears to correspond to the Manitoulin dolomite of southern Ontario; but the upper, more ferruginous part may correspond approximately to the Cabot Head shale, which, in southern Ontario, is the horizon for *Rhinopora verrucosa*, while the genus *Brockocystis* appears limited to the Manitoulin limestone in that province.

The name Beavertown marl was not intended to designate the richly fossiliferous clay forming the upper part of the Brassfield section or included in the latter locally, but it was used to designate a soft, very fine grained deposit, an argillaceous limestone, readily disintegrating under the influences of weathering, and not a marl in any sense of the term. The term was first used in 1885,⁶ and several species, including *Platystrophia reversata*, *Ctenodonta minima*, *Liospira affinis*, *Cyclora alta*, *Bellerophon exiguus*, *Orthoceras inceptum*, and the problematical species designated as *Zygospira modesta* and *Trochonema nanum*, were described from this horizon. The large crinoid beads found in this stratum were of the same type as those found in the upper part of the Brassfield limestone, and the Beavertown marl is

⁵Foerste, A. F., Fossils of the Clinton group in Ohio and Indiana: Ohio Geol. Survey., vol. 7, 1893, pl. 31, fig. 4.

⁶Foerste, A. F., The Clinton Group of Ohio: Denison Univ. Bull. Sci. Lab., vol. 1, 1885 p. 74.

regarded as merely the upper part of the Brassfield formation in this area. A chemical analysis of this so-called marl was published in the series of articles on the Clinton Group of Ohio,⁷ the term Clinton at that time being in use for the strata now known as the Brassfield.

In the Hillsboro area, in Highland county, Ohio, the Silurian section consists of the following strata, named in descending order.

Guelph dolomite
Lilley formation
Bisher formation
Alger clay shale
Dayton limestone
Brassfield limestone
Belfast formation

The term Guelph is used here merely to avoid using the term Cedarville dolomite for strata not containing a fauna similar to that of the Cedarville area. It does, however, contain *Megalomus canadensis*, species of *Trimerella*, and other fossils known in the Guelph of Ontario. *Liospira perlata* and tall species of *Coelocaulus* occur.

The base of this so-called Guelph in the quarries in the eastern part of the town of Hillsboro is formed by a *Pentamerus* horizon which corresponds approximately to the Springfield dolomite of Greene, Clarke, Miami, Montgomery, and Preble counties, farther north in Ohio. The overlying part of this so-called Guelph should correspond in age to the Cedarville dolomite of the counties just mentioned, but it does not contain the same fauna.

The Lilley formation includes that part of the section erroneously identified many years ago by Prof. Edward Orton, as the Springfield stone.⁸ This identification was based on the lithological appearance of the rock, it forming a promising

⁷ Foerste, A. F., The Clinton Group of Ohio;—Part IV: Denison Univ. Bull. Sci. Lab., vol. 3, pp. 3-12, 1888.

⁸ Orton, Edward, The Geology of Highland County; Geol. Surv. Ohio, Rep. Progress in 1870. Published in 1871, pp. 274-277.

building stone where exposed along the abandoned railroad within the limits of Hillsboro, and in the quarry in which this railroad, as far as finished, terminated in the eastern part of the town.

The Bisher formation corresponds approximately to the West Union or Lower Cliff of Professor Orton, and this name would have been retained if Professor Orton ever had described any section from the West Union area, or had designated at Hillsboro the same boundaries between the West Union and Springfield beds as those adopted later between the Bisher and Lilley formations. It is of upper Clinton age.

Notes on Bisher and Lilley faunas were published in the Ohio Journal of Science in the years 1917 and 1919.

The Bisher fauna can be traced southward from Hillsboro throughout Highland and Adams counties, in Ohio, and Lewis county, Kentucky, as far as the northern part of Fleming county in the latter state. It has not been identified anywhere north of Hillsboro, Ohio, but the strata immediately beneath the Springfield limestone along the creek half a mile west of Port William, in the area northeast of Wilmington, Ohio, appear to contain a somewhat similar fauna. But no trace of the overlying Lilley fauna is to be found so far north.

As a matter of fact, the Lilley fauna appears to be very restricted even in the Hillsboro area. It is known at various quarries in the immediate vicinity of Hillsboro, at several localities southeast of Marshall, and apparently also 2 miles north of Locust Grove, north of Crooked Creek, on the road to Sinking Springs. It has not been identified at any other localities.

While the Bisher formation can be traced over wide areas in Highland and Adams counties, the strata overlying the Bisher formation present a complex of which very little is known so far. The lithologic character of these strata changes within a few miles on proceeding from Hillsboro eastward toward Marshall, and many fossil horizons occur in the areas between Hillsboro, Marshall, Bainbridge, and the Ohio River whose relative position remains to be determined.

Only the Bisher formation is definitely known to occur in Lewis county, Kentucky, though lower portions of the so-called

Guelph may occur there also, for instance, in those Silurian deposits which occur west of Vanceburg on the road to Valley.

The bituminous horizons of the so-called Guelph in the Hillsboro area may be traced northwest of the town on the road to Wilmington, and similar strata, but without the bituminous content, appear to occur near New Vienna, northeast of Snow Hill, in the area between New Vienna and Wilmington, Ohio.

From Wilmington northward, however, the Niagaran section resembles that found in Greene, Clarke, Miami and Montgomery counties. Here the following section is found, in descending order.

Durbin formation	{ Cedarville dolomite
	{ Springfield dolomite
	{ Euphemia dolomite
"Laurel" limestone	
"Osgood" clay shale	
Dayton limestone	
Brassfield limestone	
Belfast bed.	

In this section the strata called the Euphemia dolomite are those included by Professor Orton in his West Union bed when using that name for the tier of counties here named. It is the Mottled bed of Professor Prosser. It is frequently exposed between Springfield, Ohio, and Lewisburg, in the western part of the state, but is unknown at Cedarville, where the lowest dolomitic rock in the gorge half a mile west of town belongs to the Springfield horizon.

Immediately beneath this Springfield dolomite, in the gorge west of Cedarville, there is a clay shale, of which a thickness of scarcely 6 feet is well exposed, the basal part not being seen. This clay shale contains, at a level 2 feet below its top, *Streptelasma radicans* Hall, *Eucalyptocrinus crassus* Hall, *Schuchertella subplana* (Conrad), *Leptaena rhomboidalis* (Wilckens), *Plectambonites transversalis* (Wahlenberg), *Dalmanella elegantula* (Dalman), *Spirifer radiatus* (Sowerby), *Atrypa reticularis newsomensis* Foerste, *Dictyonella reticulata* (Hall), *Strophostylus* sp., and *Dalmanites verrucosus* (Hall). This is a Waldron fauna.

The Springfield dolomite in the Springfield area contains relatively few fossils aside from *Pentamerus oblongus* and *Calymene celebra* Raymond. However, at the Jackson quarry, several miles south of Covington, Ohio, the following fauna was found at this level:

- Cyathophyllum sp., small.
- Cyathophyllum sp., septa with dentate edges.
- Calostylis sp.
- Halysites labyrinthicus (Goldfuss)
- Syringopora sp., form similar to that found in Cedarville dolomite
- Lichenalia (?) sp., frequently twisted into more or less tubular growths as in Cedarville dolomite
- Caryocrinus sp.
- Atrypa reticularis niagarensis Nettelroth
- Camarotoechia neglecta (Hall), with relatively sharp plications
- Clorinda ventricosa (Hall)
- Dalmanella springfieldensis Foerste
- Leptaena rhomboidalis (Wilckens)
- Meristina maria (Hall)
- Orthis fissiplicata Foerste
- Pentamerus oblongus Sowerby
- Platystrophia daytonensis Foerste, with 2 plications in sinus
- Platystrophia sp., with 4 plications in sinus, found also in Cedarville dolomite at Springfield, Ohio
- Rhipidomella hybrida (Sowerby)
- Schuchertella subplana (Conrad), resembling Rochester shale form in its elongate outline
- Spirifer radiatus (Sowerby), with a few lateral plications
- Strophonella sp., resembling *Strophonella roemeri* Foerste in being strongly convex and prolonged medially
- Strophonella williamsi Kindle and Breger
- Cyclonema ohioensis (Hall and Whitfield), described originally as a variety of *Pleurotomaria pauper*
- Phanerotrema occidens (Hall)
- Trochonema sp., large, but with relatively low spire
- Calymene celebra Raymond

In the Euphemia dolomite, beneath the Springfield dolomite in the Jackson quarry, the following fossils were found:

Enterolasma caliculum
Favosites sp.
Caryocrinus sp.
Dimeroocrinus sp.
Lichenalia sp. with pseudo-tubular growth, as in Cedarville dolomite
Atrypa reticularis
Brachyprion cf. *newsomensis*
Camarotoechia neglecta
Leptaena rhomboidalis
Orthis flabellites
Pentamerus oblongus
Platystrophia daytonensis
Rhipidomella hybrida
Schuchertella subplana
Spirifer radiatus
Stropheodonta cf. *profunda*
Strophonella williamsi
Whitfieldella sp.
Diaphorostoma cf. *niagarensis*
Dalmanites cf. *limulurus*
Illaenus ioxus

In the Euphemia dolomite, in the large quarry northwest of Lewisburg, the following species occur:

Enterolasma caliculum
Atrypa reticularis
Leptaena rhomboidalis
Orthis flabellites
Plectambonites transversalis
Schuchertella subplana
Strophonella sp., strongly convex form
Whitfieldella sp., large
Diaphorostoma cf. *niagarensis*
Dalmanites cf. *limulurus*
Illaenus ioxus

At Ludlow Falls the Euphemia dolomite contains:

Striatopora sp., large form, one-third inch in diameter
Atrypa reticularis
Brachypirion cf. newsomensis
Orthis flabellites
Pentamerus oblongus
Platystrophia daytonensis
Rhipidomella hybrida

Pentamerus oblongus is fairly common in the Euphemia dolomite in some of its exposures southwest of Springfield, south of the railroad passing Cold Springs.

The Cedarville, Springfield, and Euphemia dolomites are regarded as belonging to a single formation, characterized by the fact that at a certain horizon, known, as the Springfield dolomite, the rock is separable readily into flagging, suitable for building purposes, while the Euphemia dolomite below and the Cedarville dolomite above are not suitable for flagging. The term Durbin formation is used for this formation as a whole.

At the Reinheimer quarry, south of New Paris, the so-called Laurel limestone contains *Pisocrinus gemmiformis*, and *Stephanocrinus osgoodensis*. The same species occur in the abandoned James Carl quarry, $3\frac{1}{2}$ miles southwest of Lewisburg, up a small stream west of the road to Eaton. They occur at a number of other localities in Preble county, Ohio. In Indiana both species occur in the Osgood limestone, but *Pisocrinus gemmiformis* is cited also from the lower part of the Laurel limestone. At the quarry west of Drexel Park, $\frac{3}{4}$ of a mile east of the Union road, north of the Eaton pike, *Pisocrinus gemmiformis* occurs in coarse-grained rock immediately beneath the Springfield limestone, assumed to be of Euphemia age. Immediately above the argillaceous strata which form the base of the exposed section along the creek a mile east of Leesburg, and north of the railroad, *Stephanocrinus gemmiformis* and *Stephanocrinus hamelli* were found in strata apparently belonging to the Bisher formation. Small species of *Pisocrinus* and *Stephanocrinus*, difficult to discriminate except in the presence of good speci-

mens, have a considerable vertical range in the Niagaran, and the specimens found so far at different localities and horizons in Ohio are regarded as inadequate for purposes of exact correlation. For the present, therefore, the so-called Laurel limestone of western Ohio must be regarded as identified lithologically, rather than paleontologically with the typical Laurel of Indiana.

The same statement can be made regarding the so-called Osgood clay shale of Ohio. This has been identified lithologically with a clay shale band well exposed in the upper part of the quarries southwest of Laurel, Indiana, but the fauna found in these so-called Osgood clay shales in Ohio is that of the underlying Dayton limestone, and not that of the typical Osgood formation in Ripley and Jefferson counties, in Indiana.

In the large quarry northwest of Lewisburg, Ohio, the top of the Dayton limestone contains the species usually identified as *Enterolasma caliculum* (Hall), *Atrypa reticularis* Linnaeus, *Spirifer radiatus* (Sowerby), and a *Spirifer* intermediate between *niagarensis* (Conrad) and *eudora* (Hall) in the number of its radiating plications. The middle part of the Dayton limestone here contains *Enterolasma caliculum*, *Orthis flabellites* Foerste, *Plectambonites transversalis*, *Spirifer plicatellus* Linnaeus, *Schuchertella subplana* (Conrad), and a small species of *Whitfieldella*, similar to the one most common in the Osgood and Laurel limestones of Indiana.

At Rocky Point, 3 miles northeast of Eaton, on the road to Lewisburg, the Osgood clay, overlying the Dayton limestone is 4 feet 3 inches thick, and contains the following species: *Enterolasma caliculum*, *Atrypa reticularis*, *Leptaena rhomboidalis*, *Orthis flabellites*, *Schuchertella subplana*, and the same species of *Spirifer* as that cited from the top of the Dayton limestone at the quarry northwest of Lewisburg.

From Trotwood $2\frac{1}{2}$ miles southward and $1\frac{3}{10}$ miles east, the following fossils are found in the Dayton limestone: *Enterolasma caliculum*, *Rhinopora* sp., *Clathrodictyon vesiculosum*, *Camartoechia neglecta*, *Leptaena rhomboidalis*, *Orthis flabellites*, *Platystrophia daytonensis*, *Platystrophia reversata*, and *Rhipidomella hybrida*.

At the abandoned quarry north of the Germantown pike, near the southeast corner of the Soldiers Home, west of Dayton, the following fossils are found in the Dayton limestone: *Enterolasma caliculum*, *Favosites niagarensis*, *Clidochirus ulrichi*, *Chasmatopora angulata*, *Rhinopora verrucosa*, *Coelospira* sp., *Leptaena rhomboidalis*, *Orthis flabellites*, *Platystrophia reversata*, and *Rhipidomella hybrida*.

In the quarries southeast of Dayton, and thence south and eastward, brachiopoda are scarce in the Dayton limestone, with the exception of *Pentamerus oblongus*, which is rare until the southern margin of Clinton county is reached, but which becomes common in parts of Highland and Adams counties, and reaches even the northern part of Lewis county, in Kentucky. In the eastern half of Montgomery county, and in Miami, Clarke, and Greene counties little is seen in the Dayton limestone in addition to *Favosites favosus*, *Favosites niagarensis*, and various species of *Orthoceras*, not determined.

Beginning at Centerville, and increasing in numbers at Todd Fork, north of Wilmington, additional species of corals, simple and compound, appear, reaching their maximum in Highland and Adams counties, where more than 20 species are known. The range of these corals continues into the northern part of Lewis county.

This change of fauna from a brachiopod fauna in western Ohio to a coral fauna southeastward along the line of outcrop, is the most significant feature noted so far in the distribution of the faunas of the Dayton limestone.

In Indiana, the limestone layer underlying the typical Osgood formation of that state, usually only one or two feet thick, is correlated with the Dayton limestone of Ohio, but the Indiana limestone layer is practically unfossiliferous, and the few species found have not belonged to diagnostic forms, so that they do not serve for purposes of accurate correlation.

In fact, all of the Ohio Niagaran strata present difficulties when the attempt is made to correlate them accurately with the Niagaran strata of Indiana.

While the Dayton, Osgood, and Laurel strata of Montgomery, Miami, Darke, and Preble counties bear considerable resemblance to the corresponding sections in the area immediately southwest of Laurel in Indiana, the so-called Osgood of Ohio does not carry the typical Osgood fauna of Ripley and Jefferson counties in Indiana, and the so-called Laurel of Ohio does not carry the Laurel fauna so well known in the St. Paul and Waldron areas of Decatur and Shelby counties of Indiana.

No equivalent to the Euphemia and Springfield strata is known at present in Indiana. The Cedarville dolomite of Ohio carries a fauna much nearer that of the Racine of Wisconsin and northern Illinois than that of the Louisville limestone of southern Indiana and northern Kentucky. The upper Niagaran strata of the eastern counties of Indiana carry faunas much nearer that of the Wabash area of northern Indiana than that of the Cedarville of Ohio, or the Louisville of the southern part of Indiana. Finally, the upper Laurel fauna of St. Paul has its affinities rather in the Racine faunas of Wisconsin and northern Illinois than in anything known in Ohio.

In other words, the evidence is accumulating that the Silurian strata of Ohio, Indiana, and Kentucky present a much greater complex of faunas than would be supposed by the simple alternation of limestone and clay zones in the various areas. While those unacquainted with the faunas will readily match limestones and clays of one area with limestones and clays of another area, notwithstanding great differences in faunal content, the paleontologist is not so ready to follow this procedure.* In our present state of knowledge of the Niagaran faunas, most of our correlations are worth very little, and must be considered merely tentative. There is a great lack of knowledge of the content and geographical range of the various faunas. Until this lack is supplied by accurate information, substantial progress is impossible. Detailed paleontological work on Silurian strata in Ohio, Indiana, and Kentucky has practically ceased, and until serious study again is undertaken no vital progress can be expected.

B. THE FAUNA OF THE WHIRLPOOL SANDSTONE OF ONTARIO

Very little is known of the fauna of the Whirlpool sandstone, the lowest member of the Medinan in southern Ontario. In 1919 Dr. M. Y. Williams⁹ listed only the following species from this sandstone:

Gasteropoda

Pleurotomaria sp. Niagara River

Hormotoma subulata (Conrad) ?? Glen William

Vermes (burrows and trails)

? Cornulites

From the Grimsby sandstone, in the upper part of the Medinan, he listed:

Brachiopoda

Lingula cuneata Conrad

Lingula clintoni Vanuxem

Dalmanella eugeniensis Williams

Camarotoechia (*Stegerhynchus*) *neglecta* Hall

Pelecypoda

Pterinea cf. *undata* (Hall)

Pterinea brisa Hall

Modiolopsis primigenia (Conrad)

Modiolopsis orthonota (Conrad)

Modiolopsis kelsoensis Williams

Ctenodonta machaeriformis (Hall)

Nuculites cf. *ferrugineum* Foerste

Gasteropoda

Bucanella trilobata (Conrad)

From the overlying Thorold sandstone, at the top of the Medinan, he listed:

Worm burrows

Daedalus archimedes (Ringueberg)

Arthropycus alleghaniensis (Harlan)

⁹ Williams, M. Y., The Silurian Geology and Faunas of Ontario Peninsula and Manitoulin and Adjacent Islands: Memoir 111, Geol. Surv. Canada, p. 28, 1919.

To the brief list of fossils from the Whirlpool sandstone published by Dr. Williams we here add a few obtained in the quarry a quarter of a mile west of the railroad station at Credit Forks, in southern Ontario. This quarry is located immediately north of a deep ravine crossing the railroad south of the station. The fossils were found in thin sandstone layers at the top of the Whirlpool sandstone, immediately under the basal layers of Manitoulin dolomite, in which specimens of *Leveilleites* were found. Several of these additional species from the Whirlpool sandstone evidently are merely earlier occurrences of forms already known from the Grimsby sandstone, in the upper part of the Medinan.

While some of these specimens are not sufficiently well preserved to serve as types of new species, they clearly indicate the presence in the Whirlpool sandstone of a much larger fauna than suspected formerly.

The list of species from the Whirlpool sandstone at Credit Forks is as follows:

1. *Lingula* cf. *cuneata* Conrad
2. *Dalmanella eugeniensis* Williams
3. *Schuchertella creditensis* Sp. nov.
4. *Whitfieldella circularis* Sp. nov.
5. *Modiolopsis orthonota creditensis* Var. nov.
6. *Ctenodonta* (?) sp.
7. *Ctenodonta* (?) *creditensis* Sp. nov.
8. *Ctenodonta* (?) *catractensis* Sp. nov.
9. *Liospira* (?) sp.

1. *Lingula* cf. *cuneata* Conrad

Plate XIII, fig. 9

Lingula cuneata Conrad, 3d Ann. Rep. Geol. Surv. New York, 1839, pp. 63, 64; Hall, Pal. New York, 2, 1852, p. 8, pl. 4, fig. 2e.

Specimen 10 mm. long, 6.5 mm. wide, ovate in outline, and pointed toward the beak; with a convexity slightly exceeding 1 mm. The general outline agrees more closely with that of figure 2e on the plate in the Paleontology of New York, cited above,

than with the more triangularly cuneate specimens represented by figures 2a, 2b, and 2c on the same plate.

2. *Dalmanella eugeniensis* Williams

Plate XIII, fig. 7

Dalmanella eugeniensis Williams, Geol. Surv. Canada, Memoir 111, 1919, p. 118, pl. VII, figs. 1-8.

Specimen a brachial valve, 7.5 mm. long, and 9 mm. wide; most strongly convex about 1.5 mm. from the beak, with a narrow median depression posteriorly, widening to a broad depression along the anterior half of the valve. About 8 radiating striae reach the anterior margin of the valve in a width of 3 mm., the total number on the valve being between 40 and 45.

3. *Schuchertella creditensis* Sp. nov.

Plate XIII, fig. 6

Cf. *Leptaena subplana* Hall, Pal. New York, 2, 1852, p. 259, pl. 53, figs. 8a, 8b.

Pedicel valve 15.5 mm. long, 18.5 mm. wide, with a convexity of almost 2 mm. at a point 5 mm. anterior to the beak. The valve is gently convex, without any trace of reversal of curvature anteriorly. At the posterior margin of the valve the lateral sides curve gently inward. Along the anterior margin, 7 to 8 radiating striae occur in a width of 3 mm., the alternate striae being distinctly more prominent. Along the postero-lateral margins this alternation of size is even more evident. The dental lamellae are nearly 3.5 mm. in length and diverge from each other at an angle of about 80 degrees.

The largest specimen found was 21 mm. in width.

Several small brachial valves, regarded as belonging to the same species, are much less convex than the pedicel valve here described.

4. *Whitfieldella circularis* Sp. nov.

Plate XIII, figs. 8 A, B

Cf. *Atrypa oblata* Hall, Pal. New York, 2, 1852, p. 9, pl. 4, figs. 4 a, b, c, and 5. Cf. *Whitfieldella cataractensis* Williams, Geol. Surv. Canada, Memoir 111, 1919, p. 121, pl. 7, figs. 16, 17, 18.

One brachial valve (fig. 8 A) is 11.3 mm. long, 10.5 mm. wide, and 3 mm. deep. It is quite evenly convex, except at the margins where it curves more rapidly. Concentric lines are seen near these margins. A median septum in the interior of the valve extended about 3 mm. from the beak.

A second brachial valve (fig. 8 B) is 9.3 mm. long, 9.2 mm. wide, and 2.3 mm. deep. The median septum on its interior is 2.5 mm. long.

These valves do not appear to be the young of *Whitfieldella oblata* (Hall), from the Upper Medinan of Lockport, New York. The first of the two specimens here described appears quite mature, judging from its convexity along its margins. Nor is it identical with *Whitfieldella cataractensis* Williams.

5. *Modiolopsis orthonota creditensis* Var. nov

Plate XIII, figs. 1, 2 A-G

Modiolopsis orthonota, Pal. New York, 2, 1852, p. 10, pl. 4 (bis), figs. 1 a-c.

Numerous valves, of which the largest is 21.5 mm. long, 10.6 mm. high, and 2.5 mm. deep. Specimens 16 to 18 mm. long are much more common. The cardinal and ventral margins tend to converge posteriorly. In one specimen 18 mm. long, the height of the specimen at the beak is 9 mm., while 10 mm. posterior to the beak it is 8 mm. in height. This appearance of convergence posteriorly is due in part to the rise of the umbonal part of the valves above the hinge-line. The posterior part of the ventral margin rises convexly as far as the posterior termination of the umbonal ridge, and from this point the posterior margin of the valve curves strongly forward at an angle of about

120 degrees with the cardinal margin. Along this part of its outline the posterior margin usually is only moderately convex, there being a distinct tendency toward straightening. The anterior part of the valve extends from 3.5 to 4 mm. in front of the beak. It is fairly evenly convex, its maximum convexity appearing slightly below mid-height of the valve, on account of the slight inward curvature of this outline on approaching the umbonal part of the valve. The umbonal part is relatively broad, and only slightly elevated above the cardinal margin. The umbonal ridge is sigmoidal in direction, starting near the beak at a small angle with the cardinal margin, this angle increasing to 20 and 25 degrees near mid-length of the valve, and then decreasing again posteriorly as far as the posterior angle of the valve. The post-umbonal slopes of the valves are distinctly concave, but the umbonal ridge tends to be rounded, rather than angular. In most specimens the middle part of the valves, beneath and anterior to the umbonal ridge, is gently convex antero-posteriorly, with a tendency toward flattening where the mesial sulcus might appear, this sulcus usually being absent, though faintly indicated occasionally.

Remarks.—These specimens from the Whirlpool sandstone at Credit Forks, Ontario, differ from typical *Modiolopsis orthonota* from the Grimsby sandstone at Lockport, and Medina, New York, in the greater angulation of the posterior side of the umbonal ridge and in the more distinctly concave curvature of the post-umbonal slope, between the umbonal ridge and the hinge-area.

Owing to its more angular umbonal ridge, the specimen represented by figure 1 on plate XIII may be designated as *Modiolopsis orthonota perumbonata* Var. nov.

In the type specimens of *Modiolopsis orthonota* that part of the shell which corresponds to the angular part of the umbonal ridge of the Credit Forks specimens is more evenly rounded while the distinctly concave part is narrower, its lower margin deviating only 2.5 mm. from the hinge-line at the posterior end of the shell. Immediately beneath the beak of the right valve the hinge-area appears to have been slightly elevated in a more or

less vertical direction, while a corresponding elevation occurred immediately in front of the beak of the left valve. The elevations may be regarded as incipient teeth. (Plate XIV, figs. 7 A, B.)

The fauna described by Hall from strata 50 to 60 feet below the top of the sandstone at Medina includes *Lingula cuneata*, *Modiolopsis orthonota*, *Modiolopsis primigenia*, *Pleurotomaria pervetusta* and *Bucanica trilobita*. This appears to be a Grimsby sandstone fauna. *Modiolopsis primigenia* is represented by fig. 8 on plate XIV.

6. *Ctenodonta* (?) sp.

Plate XIII, fig. 5

A single left valve, 6.6 mm. long, 4 mm. high, and 1.3 mm. deep, resembling *Modiolopsis orthonota* in outline, but without any trace of concave curvature along a distinctly defined post-umbonal slope. In fact, there is no distinctly defined post-umbonal slope, the valve rounding from the general convexity of its middle parts into a more increased convexity along the posterior cardinal margin of the shell without any interruption whatever. In specimens of *Modiolopsis orthonota* of the same size the post-umbonal slope is distinctly defined and is distinctly concave.

7. *Ctenodonta* (?) *creditensis* Sp. nov.

Plate XIII, fig. 3

Three valves in which the ratio of the height to the length varies from 71 to 76 per cent are at hand. In the two larger specimens the posterior part of the outline is defective. One of the specimens (fig. 3) is 8.5 mm. in height, and its length is estimated at 11.8 mm. In the other one of the larger specimens the height is 7.5 mm., and the length is estimated at 10.5 mm. The third specimen is 4.2 mm. in height and 55. mm. in length. The larger specimens are 2 mm. in depth. The anterior parts of these valves are similar to those of *Modiolopsis orthonota*, but the beak is more pointed and is directed more distinctly toward the front, and the upper half of the anterior outline, anterior to

the beak, is more distinctly concave. Posterior to the beak there is no trace of an umbonal ridge, the convexity of the valves increasing toward the cardinal margin. The posterior margin of the valves is similar to that of a relatively short *Ctenodonta*.

8. *Ctenodonta* (?) *cataractensis* Sp. nov.

Plate XIII, fig. 4

Left valve 7.3 mm. long, 5.5 mm. high, and 1.5 mm. deep. General outline elliptical, with the longer axis in a horizontal direction, but with the beak sufficiently elevated to add a slight triangularity to the elliptical outline. The beak is about 3 mm. from the anterior margin. The outline posterior to the beak is convex as far as the posterior angle of the valve. The outline anterior to the beak is almost imperceptibly concave. The ventral outline is evenly convex along the greater part of its length, this convexity increasing toward the extremities of the valve, where the outline is most rapidly rounded. The maximum depth of the valve is about 2 mm. below the beak.

9. *Liospira* (?) sp.

Plate XIII, fig. 11

Specimen with a maximum transverse diameter of 5 mm., consisting of at least two volutions. Evidently only a part of the shell is preserved, the number of additional volutions in a mature specimen being unknown. The spire is depressed, very much as in *Liospira micula* (Hall), from the Ordovician. The outer margin is narrowly rounded, also as in *Liospira micula*, and not elevated as in *Pleurotomaria* (?) *pervetusta* (Conrad), in which the height of the spire and of the individual volutions is much greater. With only a single specimen at hand it is impossible to determine with confidence either its relationship to, or its difference from *Pleurotomaria pervetusta*. It may be the apical part of the latter species.

Straparollus (?) pervetustus (Conrad)*Plate XIV, fig. 6*

Cyclostoma ? pervetusta Conrad, Ann. Rep. New York State Geol. Surv., 1838, p. 113; *ibid.*, 1839, p. 65.

Pleurotomaria pervetusta Hall, Pal. New York, 2, 1852, p. 12, pl. 4 (bis), figs. 3 a-d.

Euomphalus pervetustus Hall, Geol. New York, 4, 1843, p. 48, figs. 1, 2; tab. ill. 2, figs. 1, 2.

Straparollus pervetustus D'Orbigny, Prod. de Pal., 1, 1849, p. 30 (gen. ref.).

Euconia (?) pervetusta Grabau and Shimer, N. A. Index Fossils, 1, 1909, p. 642, fig. 874.

Shell 9 mm. wide and 7.5 mm. in height, with the spire rising 3 mm. above the last whorl near the aperture. In the specimen figured by Hall the width is 8 mm., the height is 6 mm., and the elevation of the spire above the aperture is about 2.5 mm. The vertical outline of the spire is rounded, the lowest volution permitting slightly more than half of the preceding volution to be seen, while toward the apical end less and less of the preceding volutions remains visible. About five volutions are present. Viewed from the exterior of the shell, these volutions appear circular in cross-section, but along vertical sections of the shell it is seen that later volutions are in contact with earlier volutions in such a manner that the inner half of the upper outline of the lower volution comes in contact with the outer half of the lower outline of the preceding volution along a lunate curve with its concave side facing upward and inward. Toward the aperture this lunate line of contact may be 2.5 mm. in width. At the base of the specimen there is an umbilicus 1 mm. in diameter. It is not known to what extent the interior of the umbilicus is lined by a callous deposit, if any be present. No trace of surface markings of any kind have been discovered.

Locality and formation.—At Medina and Lockport, in the Grimsby sandstone member of the Medinan.

Remarks.—Until traces of a slit-band are discovered in this species it seems inadvisable to refer it to *Pleurotomaria* or to

any of the Pleurotomariidae. It does not possess the conical spire of *Euconia*. Externally it resembles such forms as *Straparollus hippolyta* Billings, and *Straparollus mopsus* Hall, but its umbilicus is much smaller. While the relationship of this species to *Straparollus* must remain in doubt, in the absence of any knowledge of the surface features, it is not out of place to refer to the absence of definite knowledge of any structure indicating affinities with the Pleurotomariidae.

C. FOSSILS FROM THE BASE OF THE MANITOULIN LIMESTONE AT
CREDIT FORKS, ONTARIO

For many years it has been customary to refer certain flat branching structures found in Ordovician and Silurian strata to the algae. Some of these, in more recent years, have been regarded as due to worm borings, worm tracks, and even to the cutting action of flowing water. Those, however, which consist of thin black films can not be passed over so lightly, and must be regarded as at least of organic origin.

The black coloring of the latter specimens usually is regarded as due to plant origin, being derived in a manner analogous to the derivation of coal from plant material.

Usually this black material, in the plant-like organisms found in Ordovician and Silurian strata, does not present any structure.

In the summer of 1911, however, the writer found numerous fragments of plant-like fronds in one of the quarries at Credit Forks, in southern Ontario, Canada, which under the microscope presented distinct, though limited evidence of structure. During the geological congress held in the summer of 1913 the writer served as guide to a small party of geologists, and on this occasion Chris Andrew Hartnagel of the Geological Survey of New York and Dr. E. O. Ulrich of the United States Geological Survey found the remarkable specimen here described as the type of the genus *Leveilleites*.

At first these frondose specimens were regarded as belonging to the algae, and an attempt was made to find algal forms with corresponding outlines. The reticulating fibers forming the body of the fronds were interpreted as corresponding to the

filaments or laciniae which traverse the interior of some of the more fleshy algae.

However, the fibrous structures traversing the interior of algae possess such a small quantity of carbon that it is difficult to conceive how they could remain in a fossil form as anything but the thinnest imaginable traces. In *Leveilleites*, on the contrary, they appear like fibers which had not given way to pressure. In fact, they appear more like fibers of sponges than of fibers which could have originated from algae.

Moreover, in the frondose fleshy algae it seemed reasonable to expect occasional traces of organs of reproduction, in the form of swellings of the fronds or other structures of sufficient size to warrant their recognition even in fossil form, but nothing of the kind was discovered among the numerous specimens examined.

In fact, as more material accumulated, the plant origin of these frondose organisms found at Credit Forks seemed less certain, and the possibility of their being of animal origin less doubtful.

The reference, in preceding lines, to fibers of sponges is not intended to suggest that *Leveilleites* may be some early type of sponge. It is possible that some other form of animal life with more or less fibrous material within its structure, not yet clearly recognized, may have existed in Ordovician and Silurian times.

Since these frondose organisms found at Credit Forks present more structure than any similar flat plant-like bodies found heretofore, they are described and figured in much greater detail than otherwise would prove desirable. In the twelve years which have elapsed since their discovery, no additional information has been added as the result of further study either of old material, or material accumulated more recently. Therefore, it does not seem advisable to withhold the publication of these observations any longer.

To the account of *Leveilleites* is added a description of *Dictyonema scalariforme creditensis*, Foerste found in the same slabs of rock as *Leveilleites*. Several species of fossils found in the

Whirlpool sandstone, directly beneath the layers containing the *Leveilleites*, have been described already, on preceding pages.

***Leveilleites* Gen. nov.**

Specimens consisting of linear-oblong frond-like expansions attached to a more or less twisted stipe. Each lateral margin of these frond-like expansions is formed by a single series of lobes, the lobes being small, and those belonging to the same expansion being approximately of the same form and size.

The frond-like expansions are flat and thin. Their median line, when the specimens are well preserved, is occupied by a narrowly linear black film within which no structure has been observed. In some specimens corresponding films occupy the median part of the lateral lobes. The significance of these linear black films is unknown. Although they occupy the position of a rachis, they apparently do not locate a line of thickening of the frond.

The lateral parts of the frond-like expansions, as far as any structure has been observed, consist of fibers, more or less irregularly arranged. In most specimens these fibers anastomose more or less irregularly, but in a few many of the meshes are approximately of the same size, usually not exceeding 0.25 mm. in diameter. Where the narrowly linear black film along the median line of the frond-like expansions is absent, the fibrous structure characterizing the lateral parts of these expansions is seen. This adds to the difficulty of finding a reasonable interpretation of the significance of the linear median black films. In some specimens, the fibers belonging to the lateral parts tend to radiate more or less on approaching the margins of the lobes.

The entire surface of the frond appears to be covered by a coat of very fine hair-like fibers. These fibers are seen most readily along the margins of the lobes, beyond which they project outward a distance varying from less than 1 mm. to fully 1.5 mm. The finer fibers number here from 5 to 7 or 8 in a width of 0.5 mm.

In some specimens, black dots are seen in addition to the anastomosing black fibers within the body of the frond-like

expansions. These black dots tend to occur in rows, about 5 or 6 in a width of 0.5 mm. Possibly these black dots locate extensions of some of the anastomosing fibers, and served as supports of very fine hair-like fibers, similar to those seen along the lateral margins of the fronds. This appears to be confirmed by some specimens in which some of the hair-like fibers extending beyond the margins of the lobes can be traced at their proximal ends to dots located some distance back from these margins, along the flat faces of the fronds.

Similar hair-like fibers cover the surface of the dichotomously branching frond-like expansions occurring in the Cayugan of the Buffalo area of New York, and in the Kokomo formation of northern Indiana. These Upper Silurian frond-like expansions usually are referred to *Buthotrephis*, a genus originally described from the Chazy and Trenton of New York.

While it is customary to refer these Upper Silurian forms of *Buthotrephis* to the algae, it should be remembered that no evidence of structure within the frond or of characteristic forms of reproduction have yet been adduced in proof of this view.

The black coloring of the specimens of *Buthotrephis* from the Buffalo and Kokomo areas usually is regarded as evidence of plant origin, the black coloring being regarded as being derived from plant material, like coal. However, it is exceedingly doubtful whether such minutely fibrous structures as those here described in *Leveilleites* ever could have had a plant origin, considering the perfection of their preservation.

Under a microscope, the fibers of *Leveilleites* are seen to pass between the minute sand grains forming the matrix as though these fibers had some measure of stiffness at the time of their burial in the sea mud. Apparently they were more or less free from other material.

These fibers resemble the fibers of sponges more than those of plants. However, even if of animal origin, the fronds of *Leveilleites* show no trace of oscula or of other characteristic structures of sponges. Possibly they belong to some group of animals not yet discriminated from those recognized so far.

Among the living algae most closely resembling the fronds of *Leveilleites* in general outline are *Leveillea jungermannoides* (Mart. & Her.) Harvey and *Polyzonia elegans* Suhr. Both belong to the family Rhodomelaceae of the class Rhodophyceae, or Red Algae and both occur in the waters off Mauritius. The first of these species is figured by Engler and Prantl in *Die Natürlichen Pflanzenfamilien* (I Theil, 2 Abtheilung), on page 463 of their volume on Algae, a generic description being given on the following page. Since the resemblance in general outline is quite striking, the term *Leveilleites* is here proposed for the Canadian frond-like expansions here described, without intending to convey any belief that these Canadian forms are algae.

The genus *Caulerpa*, belonging to the class Chlorophyceae, or Green Algae, also presents lobate frondose expansions; this is true especially of *Caulerpa crassifolia* (Ag.) J. Ag., shown on page 136 of Engler and Prantl, but this is a much larger form than *Leveilleites*.

Among Hepaticae, there are foliose species of *Calypogeia* (= *Kantia*), *Lophocolea*, *Chiloscyphus*, etc., but Hepaticae probably were not in existence in Silurian times; at least they are not known to have occurred in the Silurian.

The genotype of *Leveilleites* is *Leveilleites hartnageli* Foerste.

***Leveilleites hartnageli* Sp. nov.**

Plates IV-XI

Type.—Specimen (plate IV, fig. A) 70 mm. in length, consisting of a stipe over 40 mm. in length, to which 12 or more frond-like expansions are attached. The frond-like expansions are about 20 mm. in length and from 3 to 4 mm. in width. The median line of the expansions is occupied by a narrowly linear black film, from one-third to two-fifths of a millimeter in width. In its present state of preservation, the divisions between the lateral lobes continue almost or quite to the continuous median black film. The number of lateral lobes of the frond-like expansions varies from 6 to 8 in a length of 10 mm., 7.5 lobes being the most frequent number.

This type specimen is associated on the same slab with *Dictyonema scalariforme creditensis* Foerste, and was found in the basal part of the Manitoulin dolomite, directly over the Whirlpool sandstone, the two lower members of the Medinan formation in southern Ontario. It was found in the quarry a quarter of a mile west of Credit Forks station, on the northern side of the deep valley which crosses the railroad south of the station. Here the Whirlpool sandstone forms the base of the quarry, and *Leveilleites* occurs in fair abundance in the basal layers of the Manitoulin dolomite, which here is quarried extensively.

Associated with *Leveilleites* in other slabs from the same locality and horizon are *Leptaena rhomboidalis* Wilckens and a species of coral resembling *Enterolasma facetus* Foerste in size and form. The *Leptaena* is 23 mm. in width. The coral is 25 mm. in length, measured along its convex side, and 15 mm. in diameter at the top. It is curved at the base very much as in figure 5, plate V, of Dr. M. Y. Williams' memoir.¹⁰ These fossils indicate the marine character of the deposits containing *Leveilleites*.

The type of *Leveilleites hartnageli* belongs to the collection of C. A. Hartnagel, a member of the Geological Survey of New York. The reverse of the same specimen belongs to the collection of Dr. E. O. Ulrich, of the United States National Museum.

The species is named in honor of Mr. Hartnagel, one of the original collectors.

Similar specimens.—Among the numerous separate fronds of *Leveilleites* found at the type locality and horizon, those represented by figures 4, 5, 6, 11, and 12 on plate V are similar in presenting 6 to 8 strongly divided lobes in a length of 10 mm.; figure 26 on plate IV is the reverse of figure 5 on plate V. Specimen 5 is represented also on plates VII and X, and specimen 26 is represented also on plate VII.

In specimen 4 the lobes are convexly curved on the side exposed to view, and they evidently are continuous laterally, the

¹⁰ Williams, M. Y., The Silurian Geology and Faunas of Ontario Peninsula and Manitoulin and Adjacent Islands: Geol. Surv. Canada, Memoir 111, 1919.

appearance of separation being due chiefly to the presence of matrix along the depressed parts of the frond.

Of specimen 5 both the obverse and reverse are present. The lobes are distinctly separated, and incline so that the upper margin of each lobe is at a higher level than the lower margin of the next lobe, when the frond is held horizontally. Hair-like fibers extending from the margins of the lobes for a distance of 1 mm. are numerous, and some of these are directed distinctly at an angle with the plane of the lobes. Apparently these hair-like fibers were attached in part to the flat faces of the lobes. Six occur in a width of 0.5 mm. Reticulation among the fibers forming the lobes is present. Series of minute dots may be recognized among the reticulating fibers. These served as points of attachment for the hair-like fibers.

Specimen 6 presents a median, rachis-like film 0.4 mm. wide. The lobes slope, as in the preceding specimen. The hair-like fibers attached to the flat surface of the fronds are clearly shown, and several of these are replaced by rows of distinct black dots, 7 or 8 in a length of 0.5 mm., interpreted as denticulations on the lateral margins of these fibers. Viewed from the side, the reticulating fibers forming the fronds present approximately circular, rather than flattened cross-sections.

Specimen 11 shows a tendency toward distinct lobes. Both reticulated and hair-like fibers are present. In addition there are several rows of black dots. Some of the hair-like fibers appear to arise from these dots and to extend beyond the margin of the frond.

Specimen 12 presents similar rows of black dots, both among the reticulated and among the hair-like fibers. Among the latter the dots are distinctly smaller. Of the larger black dots in the frond 6 occur in 1 mm.; on the hair-like fibers 5 to 7 dots occur in 0.5 mm. Some of the hair-like fibers are 1.5 mm. long.

Specimens with more numerous lobes.—In the specimens represented by figure 3 on plate V and figure 20 on plate VI, more numerous lobes occur, than in the specimens described so far. The first of these specimens exposes several fronds with 9 or 10 lobes in a length of 10 mm.; the second has 11 lobes in the same length.

Specimen 3 is represented by both the obverse and reverse parts. In specimen *B* the lateral margins of the lobes appear confluent. In several small fragments between *A* and *B* the lobes are conspicuously separated from one another; possibly only the median parts of these lobes are preserved. In *B*, the rachis-like median film is 0.5 mm. wide. The reticulating fibers appear to radiate more or less toward the margin of the lobes. Numerous hair-like fibers, 1 mm. in length, extend beyond the margin of the frond. Among the reticulating and hair-like fibers there are rows of black dots, those among the hair-like fibers being smaller.

In specimen 20, the left margin of the frond is distinctly lobed, while the right margin is only crenulated. Apparently the marginal parts of the lobes are not well preserved on the distinctly lobed side. Rows of black dots appear both among the reticulated and among the hair-like fibers.

Appearance of lobation sometimes deceptive.—Some specimens which on macroscopical examination appear strongly lobed, on microscopical examination appear less indented, the lateral parts of the supposed lobes being confluent, the lobation being confined to marginal crenulations. Specimens of this type are represented by figures 1, 7 A, 8, 9, and 10 on plate V, and by figures 18 B and 21 on plate XI. Additional figures of specimens 8, 18 B, and 21 are found on plates VIII, XI, and IX respectively.

Frond A on specimen 1 presents very well the median black rachis-like film. Rows of black dots are very distinct, varying from 6 to 9 in 1 mm.

Specimen 8 shows very well the median rachis-like film of the frond, 0.4 mm. wide. The fibers within the frond form relatively coarse and irregular meshes. Along the central part of the frond, black dots occur in series, 5 or 6 in 0.5 mm. The hair-like fibers extend 1 mm. beyond the margin of the frond. Black dots along these hair-like fibers number 6 or 7 in 1 mm. The hair-like fibers probably were attached both to the margin of the frond and to its flat faces.

Specimen 10 shows very well the reticulation among the fibers forming the body of the frond. The hair-like fibers extending beyond the margin of the frond are also well preserved. Specimen 18 B exposes very well some of the hair-like fibers near the lateral margin of the frond. The appearance of lobation is due to oblique wrinkling. Frond B on specimen 18 is one of the best specimens to suggest the presence of reticulations among the fibers of the frond. Near the median line of the frond 3 meshes occur in a length of 1 mm.; at a greater distance from the median line they are more irregularly arranged. Of the larger black dots, 5 occur in a length of 1 mm. Specimen 21 shows along its right margin several of the series of black dots regarded as locating the direction of some of the hair-like fibers.

In specimen 23 the right hand frond is seen under the microscope to be crenulated rather than lobed, the appearance of lobation being due in part to a twisting of the frond near the inner angles of the points of indentation. The median rachis-like film is poorly preserved, but may be traced readily. Reticulation among the fibers of the frond is evident. The hair-like fibers extend more than 1 mm. beyond the margin of the frond, and some of them may be traced to points of attachment on its flat surface.

In specimen 22 the rachis-like film of the median part of the frond is 0.6 mm. wide, the corresponding parts of the lateral lobes being 0.25 mm. wide. The reticulated fibers produce meshes from 0.2 mm. to $\frac{1}{3}$ mm. long. Along some of the hair-like fibers there are 6 or 7 dots in a length of 0.5 mm.

In specimen 24 the main rachis is 0.6 mm. wide, while the corresponding parts of the lateral lobes are 0.4 mm. wide. The latter are so well preserved that on macroscopical examination the frond appears lobed, while microscopically the frond is seen to be merely crenulated.

Specimens with crenulated margins.—Specimens with the lateral margins of the frond-like expansions crenulated rather than lobed are so common that eventually they may be regarded as more normal than the lobed specimens of *Leveilleites*. Specimens with crenulated edges are represented by figures 2, 3A,

and 7B on plate V, by figures 13, 14, 15, 16, 17, 18A, 19, and 21A on plate VI, and by figure 25 on plate IV. Additional figures of 3A, 21A, and 25 are presented on plates VII and IX.

In specimen 2 the median rachis-like film is 0.4 mm. in width. Among the reticulating fibers several series of black dots number 6 or 8 in a length of 0.5 mm. Hair-like fibers extending beyond the margin of the frond are well shown.

Specimen 3A shows traces of the median rachis-like film. Some of the meshes enclosed by the reticulated fibers are about 0.2 mm. in diameter. Distinct black dots near the median part of the frond number 5 in 0.5 mm. Some of the hair-like fibers present similar series of dots of smaller size, regarded as denticulations on the sides of these fibers. The larger dots within the flat area of the frond may have served as points of attachment of some of the hair-like fibers.

The frond in the lower right-hand corner of specimen 7 has a rachis-like film 0.5 mm. wide. The black dots belonging to the reticulating fibers number 5 in 0.5 mm. Those belonging to the hair-like fibers number 7 in the same distance.

In specimen 13 the main rachis-like film is 0.7 mm. wide, the corresponding parts of the lateral lobes are 0.4 mm. in width. The specimen 14 has a main rachis-like film 0.4 mm. wide, the lateral median films being 0.3 mm. in width. The frond apparently was about 0.1 mm. thick. Seven black dots occur in a length of 0.5 mm. on the surface of the frond, but these dots are as fine as those belonging to the hair-like fibers. In specimen 15 the width of the rachis-like film is 0.5 mm. In specimen 16 its width is also about 0.5 mm. The corresponding lateral films are 0.3 mm. wide. Black dots tend to occur locally in diagonally intersecting series. Between 6 and 7 dots occur in a length of 1 mm., apparently serving as points of attachment for the hair-like fibers. In specimen 17 the main rachis-like film is from 0.7 to 0.8 mm. wide; the corresponding lateral structures are 0.4 mm. wide. Near the margin of the frond 4 to 5 black dots occur in a length of 0.5 mm.

In specimen 18A the rachis-like film is 0.3 mm. wide. The substance of the frond evidently consists of something more than

a thin carbonaceous film, the reticulating fibers being distributed through a visible thickness of the matrix, though possibly scarcely a 0.1 mm., in this dimension. The reticulation of the fibers of the frond can be recognized locally. The hair-like fibers extend 2 mm. beyond the margin of the frond. They arise apparently from black dots on its flat surface.

In specimen 19 the rachis-like film is 0.5 mm. wide. The reticulated structure of the fibers forming the body of the frond is visible. From 4 to 6 hair-like fibers occur in a width of 0.5 mm. along the margin of some of the lobes. From 6 to 7 dots may be recognized in a length of 0.5 mm. along some of these fibers.

In specimen 21A the rachis-like film, 0.5 mm. wide, is distinctly shown, and the series of dots belonging to the fibers along the margin of some of the lobes are distinctly visible. Of the larger black dots, 6 or 7 occur in 1 mm.

In specimen 25 the median rachis-like film is 0.4 mm. wide; the corresponding structures of the lateral lobes are far less distinctly outlined. The appearance of reticulation among the fibers forming the frond is strikingly shown. Some of the meshes are 0.4 mm. long and 0.2 mm. wide. On close examination many of these fibers appear to be supplied by a series of dots, varying from 5 to 7 in a length of 0.5 mm. Some of those near the margin of the frond serve as points of attachment for the hair-like fibers. At one point numerous hair-like fibers may be traced for almost 3 mm. beyond the margin of the frond. They are shown best near B as located on plate IX.

Buthotrephis Hall

The genus *Buthotrephis* was founded by Hall¹¹ on *Buthotrephis tenuis* Hall, from the Trenton of New York, and not on *Buthotrephis antiquata* Hall, from the Chazy of that state. This is evident from his statement in the description of *Buthotrephis antiquata* that "In the present genus, the typical form is to be found on plate 21, fig. 1," where the genotype is erroneously

¹¹ Hall, James, *Paleontology of New York*, vol. 1, p. 8, 1847.

portrayed under the name *Buthotrephis gracilis*, a name previously used by Hall in 1843¹² for a Clinton form of New York. In the second volume of the Paleontology of New York (p. 18) Hall corrected this error and introduced the name *Buthotrephis tenuis* for this genotype.

In describing *Buthotrephis tenuis* Hall states that "A carbonaceous film is all that remains of the fossil," and also that this fossil is found "upon a shaly carbonaceous film on the limestone."

In his original description of the genus Hall defines the latter as follows: Stems subcylindric or compressed, branched; branches numerous, divaricating, leaflike; structure vesicular?

Little appears to be gained by a study of the Trenton type. In his study of two species from the Kokomo member of the Cayugan, at Kokomo, Indiana, however, Dr. David White makes some observations which may prove illuminating in connection with the structure of the genus *Leveilleites*. He describes the fronds of *Buthotrephis divaricata* White¹³ as rugulose or minutely granulose, and marked, especially along the medial portion, by very delicate, irregularly, but more or less obliquely, arranged trichomatose or filamentose impressions. Without a central axis or strand. Vague globular bodies near or at the apices of the branches. Similarly he describes the texture of *Buthotrephis newlini* White¹⁴ as slightly rugose, marked by irregular, very slender, intermingled and tangled trichomatose or filamentose elements, those near the center being coarser, often thread-like, and more or less longitudinal in their arrangement. Similar filamentose texture occurs in *Buthotrephis lesquereuxi* Grote and Pitt, from the Bertie member of the Cayugan at Buffalo, New York. Here there is an irregularly woven or cloth-like mesh.

More recently, specimens referable to *Buthotrephis lesquereuxi*

¹² Hall, James, Geology of New York, part 4 (fourth district), p. 69, fig. 14.

¹³ White, David, Two new species of Algae from the upper Silurian of Indiana: U. S., Nat. Mus., Proc., vol 24, pp. 265-270, pl. 16, 1902. See also Proc. Biol. Soc. Washington, 15, 1902, p. 86.

¹⁴ Idem. p. 266, pls. 17, 18.

have been studied by Dr. Rudolph Ruedemann,¹⁵ and have been referred by him to the genus *Inocaulis*. Figure 4 on plate 4 of his account shows in striking manner the black dots on the surface of the frond, evidently serving as points of support of the hair-like fibers which evidently cover the entire surface of the frond, but which are seen best where projecting beyond its margins. According to Dr. Ruedemann the surface of the frond-like growth is covered with fine tubercles in some places and with fine pores in others. The tubercles are the casts of the pores, so that the entire surface of the organism appears covered with pores. The pores terminate in fine straight tubes having the dimensions of fibers, more or less perpendicular to the surface of the frond. Of the circular pores 5 occur in a length of 1 mm. The width of the hair-like tubes is 0.05 mm. The original form of the branches of the frond is regarded as having been cylindrical in form. Such fibers as appear within the fronds appear twisted together irregularly, rather than forming reticulating meshes. The structure is regarded as graptolitic, allied to *Inocaulis*, *Palaeodictyota*, *Acanthograptus*, and the like. The possibility of the fibers being chitinous, rather than carbonaceous, is indicated.

It is evident that *Leveilleites* presents structures suggestive of the Kokomo and Buffalo forms formerly referred to *Buthotrephis*. There is a possibility of their being of animal, rather than of vegetable origin. As to their affinities to the Dendrograptidae among the Dendroidea order of the graptolites, the present writer is in no position to express any opinion, not being sufficiently familiar with the latter.

***Buthotrephis creditensis* Sp. nov.**

Plate XV A, figs. 15 A, B

Flat fronds, known only from fragments 65 mm. long and 30 to 35 mm. wide; originally probably similar in size and shape to

¹⁵ Ruedemann, Rudolph, Account of some new little-known species of fossils, mostly from the Paleozoic rocks of New York: N. Y. State Mus. Bull. 189, 1916, pp. 13-17, text fig. 4 and pl. 4, figs. 1-4.

the specimen of *Phaenopora expansa* Hall and Whitfield, illustrated in 1893,¹⁶ excepting that one of the specimens has a more distinct lobation along one part of its margin. None of the specimens are dichotomously branched as in the species of *Buthotrephis* described from the Bertie member of the Cayugan in the Buffalo area of New York, or those described from the Kokomo member of the Cayugan of northern Indiana. Although to the unaided eye these fronds appear flat and continuous, under the microscope the frond appears to possess a structure consisting in part of longitudinal lines connected by cross lines, producing oblong or oval meshes, the whole somewhat resembling a *Dictyonema*. Of the more or less branching longitudinal lines there usually are from 7 to 8 in a width of 5 mm. Of the oblong or oval meshes there are about 5 or 6 in a length of 5 mm. It is impossible to determine from the material in hand how the walls of these meshes are constructed. Apparently they are built up of fibers, more or less reticulating, so as to produce narrow walls more or less vertical to the plane of the fronds, at least along that part of the walls which lies nearest the surface of the frond. The inner part of the frond appears to consist of a continuous sheet of black material, although it is possible that here the fibers are merely more closely interlaced. It is impossible to determine whether the oblong or oval meshes occur only on one side or on both sides of the frond. If they locate anything corresponding to zooecia, it has been impossible to verify this fact.

Locality and formation.—Associated in the same fragments with *Leveilleites* in the basal members of the Manitoulin dolomite, at Credit Forks, Ontario.

***Dictyonema scalariforme creditensis* Var. nov.**

Plate IV, fig. B

Dictyonema scalariforme Foerste, Bull. Sci. Lab. Denison Univ., 2, pt. 1, 1887, p. 108, pl. 8, figs. 28, 29; Geol. Surv. Ohio, Pal. 7, 1893, p. 600, pl. 27, figs. 28, 29.

¹⁶ Foerste, A. F., Fossils of the Clinton group in Ohio and Indiana: Ohio Geol. Surv., vol. 7, pl. 29, 1893.

Rhabdosome originally infundibuliform, with sides diverging at angles varying in different specimens from 45° to 75° . The base of this rhabdosome tends to be pointed. Its length usually is from 25 to 30 mm. Between 12 and 15 branches occupy a width of 10 mm. The branches vary from 0.3 to almost 0.5 mm. in width, and tend to be narrower than the spaces between them. Usually the branches are almost straight. They are connected by dissepiments forming large angles (usually nearly right angles) with the branches. Seven or 8 of these dissepiments occur in a length of 5 mm. Along the greater part of their length these dissepiments are only slightly larger than 0.05 mm., but they enlarge near contact with the branches. The resulting meshes are quadrangular. The apertures of the thecae are not distinctly preserved in any specimen at hand but in several specimens the worn surfaces show rounded or elliptical outlines which are regarded as locating the thecae. Of these there are about 9 in a length of 5 mm., the number decreasing in some specimens to 8 in this distance.

Locality and formation.—In the quarry north of the deep ravine at Credit Forks, Ontario, a quarter of a mile west of the railroad station. In the basal part of the Manitoulin dolomite, a member of the Medinan.

Remarks.—In the original description of *Dictyonema scalariforme* the number of thecae was given as 13 in a length of 5 mm. Since in the Credit Forks specimens only 9 were noticed in the same distance there is a possibility that a distinct form here is represented, for which the name *Dictyonema scalariforme creditensis* is proposed.

D. A LOWER MEDINAN FAUNA BELOW THE BRASSFIELD LIMESTONE
IN OHIO

In the quarry half a mile northeast of Centerville, Ohio, and about $\frac{1}{3}$ of a mile northwest of the railroad station, the full section of the Brassfield limestone and of the Dayton limestone is exposed. At one point the Dayton limestone is overlain by the lower part of the argillaceous layers formerly known as the Niagara shale, and at present doubtfully referred to the Alger

shale. Beneath the Brassfield limestone there are about 4 feet of argillaceous material weathering into a gritty clay. The latter has recently been traversed by ditches, and numerous gastropoda, of strongly Ordovician aspect, have been exposed. In addition there is a species of *Ctenodonta* and of one *Spyroceras*, both of which have Ordovician affinities. The brachiopoda, on the contrary, are distinctly Silurian in character, and the same is true of one fragment of a pygidium of *Dalmanites*. The list includes the following:

1. *Schuchertella subplana brevior* Var. nov.
2. *Brachyprion*
3. *Whitfieldella* cf. *ovoides* Savage
4. *Bellerophon centervillensis* Sp. nov.
5. *Hormotoma trilineata* Sp. nov.
6. *Hormotoma centervillensis* Sp. nov.
7. *Liospira* (?) *depressum* Sp. nov.
8. *Lophospira ehlersi* Sp. nov.
9. *Lophospira* (*Ruedemannia* ?) *centervillensis* Sp. nov.
10. *Loxoceras husseyi* Sp. nov.
11. *Spyroceras microtextile* Sp. nov.
12. *Ctenodonta* cf. *simulatrix* Ulrich
13. *Dalmanites*

The specimens are not found in situ but occur intimately mixed together in the material thrown out from the ditch, and this material occurs in the original low ridges formed at the time these ditches were dug. Any effort to discover any other source is futile.

Since the Edgewood limestone in southern Illinois and eastern Missouri occurs below the Brassfield limestone of those states, the fauna of the Edgewood limestone, as described and figured by Savage¹⁷ was searched for possible similar species, but with no definite success. Such genera as *Schuchertella*, *Brachyprion*, *Whitfieldella*, *Bellerophon*, *Hormotoma*, *Liospira*, *Lophospira*, *Ctenodonta*, and *Dalmanites* are represented in the Edgewood limestone, and although none of the species from the Center-

¹⁷ Savage, T. E., *Stratigraphy and paleontology of the Alexandrian series in Illinois and Missouri*: Illinois State Geol. Surv. Bull. 23, 1913.

ville quarry can be proved identical with those found in the Edgewood limestone, the affinity of these specimens from the lower argillaceous strata in the Centerville quarry appears to be nearer those of the Edgewood formation than those of any other formation so far described. Additional material is needed to confirm such a correlation.

Back of a house on the west side of the road following Beasley fork southward from West Union, Ohio, there is an exposure of Belfast rock, beneath the typical Brassfield. The upper layer, 1 foot thick, is the typical Belfast. Below this is more shaly rock, containing *Enterolasma caliculum*. About 4 feet beneath the typical Belfast there is a thin argillaceous rock layer containing the Rhynchonelloid here identified as *Rhynchotrema thebesensis* Foerste, and a form resembling *Hormotoma trilineata*, Foerste, but smaller in size. Prof. W. H. Shideler, who was the first to recognize the Silurian age of these strata, found also a small form of *Whitfieldella* at this horizon.

Rhynchotrema thebesensis was found by Prof. Shideler also on the E. P. Smalley farm, about 2 miles south of Lawshe, in Adams county, where a small stream flows into Brush creek from the east. Here the Belfast bed is $5\frac{1}{2}$ feet thick.

At the Whippoorwill chapel, $2\frac{1}{2}$ miles northeast of West Union, the typical massive Belfast bed contains *Platystrophia daytonensis* Foerste and several annulated specimens of Orthoceroids, possibly *Dawsonoceras*. In the overlying thin-bedded argillaceous strata the same species occur as are found in the immediately overlying part of the Brassfield limestone. These thin-bedded argillaceous strata at the base of the Brassfield limestone, and carrying a Brassfield fauna, are especially common in the northwestern quarter of Adams county, Ohio, between Winchester, Graces Run, Seamon, and northward.

These argillaceous strata carrying the Brassfield fauna, whether these strata be thin-bedded or thicker-bedded, are distinct from the lower argillaceous strata carrying the fauna listed from the base of the Centerville quarry, the Beasley Fork locality, and the locality 2 miles south of Lawshe, on the E. P. Smalley farm. The former are clearly of Brassfield age. The

latter appear to belong to a distinctly lower horizon, possibly corresponding to the Edgewood of western Illinois and eastern Missouri.

***Schuchertella subplana brevior* Var. nov.**

Plate XIV, fig. 13

Width of shell at hinge-line 29 mm.; length 18 mm. Pedicel valve with a maximum convexity of 1.5 mm. at a distance of 3 mm. from the hinge-line, flattening out toward both the lateral and anterior margins. Radiating striae alternating in size; about 8 of the more prominent striae occupy a width of 5 mm. along the anterior margin of shell. Brachial valve more evenly convex, with the maximum convexity at about two-fifths of the length of the shell from the hinge-line.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio; in the argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—In typical *Schuchertella subplana* (Conrad) the ratio of the length to the breadth usually varies from 75 to 90 per cent, while the form here described has a ratio of only 62 per cent.¹⁸

The Waldron form, also known under the name *Schuchertella subplana*, is as short as the Centerville form, but the radiating striae are coarser. It may be known as *Schuchertella subplana waldronensis* Var. nov.

***Brachyprion* sp.**

Plate XIV, fig. 12

Shell 25 mm. in width, enlarging to 30 mm. along the hinge-line, owing to the acute extension of the postero-lateral angles. Length 21.5 mm. Only the interior of a valve is at hand and this is assumed to be the pedicel valve. The hinge-area is 1 mm. in height at the beak. On the inner surface of this valve a strong median striation extends from a short distance anterior to the beak forward to a point about half-way

¹⁸ Hall, James, Paleontology of New York: vol. 2, 1852, pl. 53.

between the beak and the anterior margin of the shell. Judging from the concavity of the inner side of this valve, the maximum convexity of its exterior was about 9 mm. from the hinge-area, and it equalled about 3 mm. From this point the convexity continued quite evenly as far as the lateral and anterior margins of the valve. The radiating striae on the outer surface of the shell were very fine and even, and numbered about 10 to 12 in a width of 3 mm.

Locality and formation.—Quarry $\frac{1}{2}$ a mile northeast of Centerville, Ohio; in the argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—*Brachyprion stropheodontoides* Savage is figured and described as rather strongly convex in the median portion of the ventral valve, and as most strongly convex in its umbonal region. There is no corresponding accentuation of the convexity of this valve in its median parts in the Centerville species here described.

Whitfieldella cf. ovoides Savage

Plate XIV, fig. 14

Whitfieldella ovoides Savage, Bull. Geol. Surv. Illinois, 23, 1913, p. 90, pl. 5, figs. 13-15; pl. 7, fig. 13.

Shell 16.5 mm. long, about 14 mm. wide, and estimated to have been about 10 mm. thick. The pedicel valve is considerably deeper than the brachial valve, and arches strongly over the latter at its beak. The shell tends to be broadest at its postero-lateral margins, about 7 mm. anterior to the beak of the pedicel valve. Anteriorly the lateral outlines converge. The anterior margin is rounded. The median part of the pedicel valve is grooved rather narrowly. Casts of the interior of the pedicel valve are fairly common, and exhibit casts of the cavity beneath the beak enclosed by the convergent dental lamellae, and casts of the impressions left by the diductor scars. The latter are striated or ridged longitudinally. The surface of both valves is rather strongly marked in a concentric manner by striae or ridges indicating successive stages of growth. Possibly these

are not so strongly marked on other specimens as on the single one at hand which shows the surface features.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio; in the argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—These Centerville specimens bear some resemblance to *Whitfieldella ovoides* Savage, from the Edgewood limestone of Illinois and Missouri and the Channahon limestone of Illinois. Better specimens are needed to make strict comparison possible.

A similar form, 13 mm. in length, was found by Professor W. H. Shideler about 4 feet below the base of the typical Belfast bed exposed 2 miles south of West Union, on the Beasley Fork road, in strata containing *Hormotoma* sp., and *Rhynchotreta thebesensis*.

***Rhynchotreta thebesensis* Foerste**

Plate XIV, fig. 15

Rhynchotreta thebesensis Foerste, Bull. Sci. Lab. Denison Univ., 14, 1909, p. 94, pl. 4, figs. 66 A-C; Savage, Bull. Geol. Surv. Illinois, 23, 1913, p. 80, pl. 4, figs. 19-20.

Valve, regarded as brachial, 16 mm. long, 16 mm. wide, with a convexity of 4 mm. Ornamented by 10 coarse, radiating plications which at the anterior margin of the shell are strongly angular and 1 mm. in height. In the absence of the pedicel valve, and without any knowledge as to the structure of the inner surface of the valve at hand, it is impossible to determine with confidence the generic relations of this valve; but, in its size and general appearance, it resembles the shell described from the Edgewood formation of southern Illinois, and eastern Missouri, under the name *Rhynchotreta thebesensis*.

Locality and formation.—Found by Professor W. H. Shideler on the E. P. Smalley farm, 2 miles south of Lawshe, on a small creek flowing into Brush creek from the east. A similar specimen was found by him also two miles south of West Union, along the Beasley Fork road, beneath a typical exposure of Belfast rock about 4 feet. The Belfast bed here is 1 foot thick.

Bellerophon centervillensis Sp. nov.*Plate XIV, fig. 20*

Shell attaining a diameter of 20 mm. in a direction across the umbilicus; but most specimens vary between 12 and 15 mm. No specimen retaining the entire width of the shell at its flaring aperture is at hand, but from such fragments as are preserved it is estimated that this aperture is at least as wide as the diameter of the shell across its umbilicus. The general cross-section of the last volution is almost evenly convex, with only a faint tendency toward angularity toward the slit-band. The slit-band varies in width from about 0.4 mm. in specimens of average size to 0.6 mm. in a few of the larger specimens. The slit-band is borne on the crest of a median carina whose elevation usually is barely $\frac{1}{3}$ mm. above the general convexity of the shell, and never exceeds 0.5 mm. The lateral walls of this carina usually rise rather abruptly. The umbilicus is small, but distinct, varying in size between that shown by *Bellerophon troosti* and its variety *burginensis*.¹⁹ Along the side of the shell, the reflexed lateral margin of the posterior part of the aperture terminates against the posterior wall of the umbilicus, and there is no evidence of a strong posterior reflexion of the posterior or inner lip of the aperture along the median part of the shell. It is possible, therefore, to see the carina and the transverse surface striae along that part of the last volution which usually, in species of *Bellerophon*, is covered by the reflexed inner lip of this aperture. The surface of the shell is covered by very fine transverse striae, strongly reflexed both laterally and toward the carina, very much as in *Bellerophon recurvus* Ulrich.²⁰

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio, in the argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—*Bellerophon centervillensis* has a decidedly Ordovician aspect. From *Bellerophon consimilis* Savage it differs in

¹⁹ Ulrich, E. O., and Seofield, W. H., The Lower Silurian Gastropoda of Minnesota: Minn. Geol. and Nat. Hist. Surv., Pal., vol. 3, 1897, pl. 64, figs. 1, 4, 6.

²⁰ Idem., pl. 64, figs. 12, 13.

being distinctly less angular along the median part of the shell, resulting in a less triangular cross-section. Unfortunately the surface striae of the Edgewood species are unknown.

***Hormotoma trilineata* Sp. nov.**

Plate XV, Fig. 6

Spire attaining a length of 32 mm., and a width of 14 mm.; apical angle usually between 28° and 33° . The number of volutions usually is 10 or 11. The sutures form an angle of about 75° with the vertical axis of the shell. The slit-band is peripheral in position; its width varies from 0.6 to 1 mm. The upper margin of the slit-band tends to be at mid-height of the volution and to form its most prominent part, while the lower margin of this band lies along the lower slope of the volution, slightly closer to the axial part of the shell. The general form of the volutions varies considerably in different specimens. Usually there is a tendency toward angularity, the margins of the slit-band being elevated slightly above the general convexity of the volutions, sometimes with a faint concave curvature of the shell both immediately above and below the band. In some specimens the concave curvature immediately above the band is quite distinct and broad. In that case there may be a faint revolving angulation about 1.5 mm. above the slit-band. Above this angulation there may be a slight flattening of the general convexity of the volutions. At the sutures the surface curves abruptly inward. On the lower slope of the last volution, at a distance of 2.5 mm. from the slit-band, there may be a second faint angulation, usually stronger than the one described first. In by far the greater number of specimens the general convexity of the volutions tends to be angulated on approaching the slit-band, and the upper half of the volutions tends to be slightly conical in slope.

Along the upper part of the shell the slit-band usually is trilineate, two very narrow sharp lines forming the lateral borders, and a broader line occupying the median line, or a position slightly above the median line of the band. The trilineate character

of the band can be detected where the diameter of the shell is only 1.5 mm. On the last one or two volutions the median line frequently becomes obsolete, and the area of the slit-band is relatively flat. Not infrequently the slit-band is strongly convex across its entire width, the bordering striae are obsolete or have weathered away, and the general resemblance of the shell is similar to that of *Lophospira producta* Ulrich or *Lophospira bowdeni* (Safford). In most of these cases the resemblance is striking only along the last 3 or 4 volutions, and the earlier volutions show the trilineate character of the slit-band with varying degrees of distinctness.

The course of the transverse striae is the same as that indicated by Ulrich²¹ in his figures of *Hormotoma*. The lunulae traversing the slit-band transversely are well shown. The apertures, as far as preserved, are similar.

Locality and Formation.—Found in the large stone quarry half a mile northeast of Centerville Ohio, in the argillaceous strata immediately underlying the Brassfield limestone.

Remarks.—The relationship of this species appears to be with *Hormotoma gracilis* Hall and *Hormotoma subangulata* Ulrich and Scofield, rather than with *Hormotoma salteri* Ulrich. At any rate, the surface of the volutions does not curve concavely upward on approaching the sutures above them.

More than a thousand specimens were examined. This accounts for the numerous variations, some of which have been noted above. Some variations are represented only by a few specimens. For instance, in some cases the angulations above and below the slit-band are very distinct, and there may be even a second angulation present above this band. Individuals with an apical angle of 37° to 40°, and with only 8 or 9 volutions, also are relatively rare, but more than 20 specimens were noted. (Plate XV, fig. 4.)

In one specimen with an apical angle of 35 degrees, 9.8 mm. wide at the base, 8 volutions are present, and 2 or 3 belong to the apical part, which is missing. The volutions in this case appear

²¹ Idem., pl. 70.

low and crowded, resembling those of *Coelocaulus oehlerti* Ulrich²² in their crowded conditions, but the spire is much shorter. (Plate XV, fig. 5.)

In a few specimens the slit-band is traversed by 3 revolving striae or lines of elevation, the two lateral ones lying closer to the median striation than to the striae forming the lateral margins of this band.

A similar form, but only 6 mm. in length and with 5 or 6 volutions, was found by Professor W. H. Shideler of Miami University at the exposure of the Belfast bed 2 miles south of West Union, on the Beasley Fork road. The typical Belfast bed here is 1 foot thick, and the specimens of *Hormotoma* are common about 4 feet beneath.

No Silurian species of *Hormotoma* with such a strongly Ordovician facies as that presented by the specimens here described are known. *Loxonema subulata* Conrad may be a *Hormotoma*, but it presents an aspect quite different from that of the Centerville specimens.

***Hormotoma centervillensis* Sp. nov.**

Plate XV, fig. 7

Spire with an apical angle of about 20° and with sutures forming an angle of about 70° with the vertical axis of the shell. The base of the shell attains a maximum diameter of 11 mm. Five volutions occur in a length of 26.5 mm., and it is estimated that the original length of the shell equalled about 36 mm., and that within this length there were 10 or 11 volutions.

Compared with *Hormotoma trilineata* the volutions are more oblique and more elongate. No tendency toward angulation of the volutions along its periphery, where the slit-band is located, is noticed. The surface here is evenly convex. The margins of the slit-band are indicated by relatively faint, and very narrow lines. The area of the band itself is flat, and shows no evidence of trilineation.

²² Idem., pl. 70, figs. 61, 62.

In one specimen the surface of the shell curves upward on approaching the suture above, somewhat as in *Hormotoma salteri canadensis* Ulrich,²³ but in the remainder this feature is not noted.

This form may eventually prove to be only one of the many variants of *Hormotoma trilineata*, but at present it appears sufficiently distinct to warrant a different name.

Locality and horizon.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio; in the argillaceous beds immediately beneath the Brassfield formation.

Remarks.—Compared with *Hormotoma subulata* (Conrad) the volutions of this species are relatively shorter. It is similar in size and in the number of volutions to *Hormotoma tenera* Savage, but the surface features of the latter are not known, so that exact comparison is impossible.

***Liospira* (?) *depressum* Sp. nov.**

Plate XIV, fig. 16

Shells attaining a height of 5.5 mm. and a maximum diameter of 13 mm. Spire very depressed. Omitting the last half of the last volution, the height of the apical part of the spire over the remainder of the shell equals slightly more than 0.5 mm.; above the aperture it rises about 2 mm., most of this elevation being due to the downward curvature of the last half of the last volution. There are 4 volutions, enlarging to a width of slightly more than 4 mm. at the aperture of a shell 5.5 mm. in diameter. Toward the apical end the cross-sections of the volutions are more nearly circular, but along the last volution the depression of the shell becomes increasingly obvious, and at the same time there is a moderate obliquity of the upper surface of this volution, especially toward the aperture. The umbilicus is about 2 mm. in diameter. Along the last half of the last volution this umbilicus is bordered by a callous deposit along the inner margin of this part of the volution. This deposit varies from 1 to 1.2

²³ Idem., pl. 70, fig. 48.

mm. in width, has a thickness of about 0.5 mm., is distinctly outlined along its convexly curved margin, and presents a steep slope on its concavely curved side, facing the umbilicus. No trace of surface markings is visible. Therefore it is impossible to determine the generic relations of this species. The fact that the callous deposit is strongly margined along its exterior border suggests that this shell may be generically distinct from *Liospira*.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Center-ville, Ohio, in the argillaceous strata immediately beneath the Brassfield limestone. Possibly a *Pycnomphalus*.

***Lophospira ehlersi* Sp. nov.**

Plate XIV fig. 17

Shell 17.5 mm. in height, with a maximum width of 15.5 mm., and an apical angle of about 80° . At the aperture the last volution has an elevation of 10 mm. There are 5 or 6 volutions, the apical one rarely being preserved distinctly. General outline similar to that of *Lophospira peracuta* Ulrich and Scofield²⁴ but with a much lower spire, somewhat as in *Lophospira tropidophora* Meek. The upper volutions expose only their upper slopes and the peripheral angle, but the second last volution exposes an increasing amount of its lower slope, so that near the aperture fully 2 mm. intervene between the peripheral angle of the second last volution and the suture beneath. The peripheral angle is more or less acute, the degree of acuteness usually being greater along the last volution. The slit-band is located on the peripheral angle. At the aperture its width is about 1 mm. or slightly more. Its upper and lower margins are defined distinctly by very fine, sharp lines. The entire width of the band is raised into an angular ridge, whose upper and lower faces form an angle of about 60° . The upper face of the slit-band slopes at about the same angle as the upper face of the volution, and the lower face of the band slopes at an angle similar to that of the lower face of the volution, the crest of the ridge formed by the band being directed upward and outward.

²⁴ Idem., pl. 73.

Near the band the upper surface of the last volution is concavely curved, and a similar concave curve marks the lower surface of this volution, at a distance of 2 mm. from the crest of the carina formed by the band. In general, the lower surface of this last volution has an outline similar to that of *Lophospira peracuta*, and the transverse striae follow a similar course, both above and below the band. A narrow umbilical opening is left between the inner lip of the aperture and the remainder of the last volution.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio, in the argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—*Lophospira ehlersi* has a distinctly Ordovician aspect. Compared with *Lophospira thebesensis* the spire is taller, and the peripheral angle is much more acute.

Named in honor of Prof. George M. Ehlers, one of the geologists active in collecting the gasteropoda of the lower strata in the Centerville quarry.

***Lophospira* (Ruedemannia?) centervillensis Sp. nov.**

Plate XIV, fig. 18

Shell 1.2 mm. in height, 11 mm. in maximum width, with the last volution occupying a height of 7 mm. near its aperture. The apical angle is about 87° . There are 6 volutions, of which the apical one scarcely ever is distinctly preserved. The slit-band is located at the angular peripheral margin, about 0.75 mm. beneath the level of the suture limiting the last volution. Above this band the surface of the volution rises only moderately toward the suture, while immediately below the band the outline of the volution is either vertical or curves slightly outward before curving inward toward the umbilical parts of the shell. In general the outline of this shell is similar to that of *Lophospira sumnerensis* (Safford), but with the peripheral angle located farther up on the volutions, the angulation of the spire resembling that of *Lophospira trochonemoides* Ulrich, but without any angulation along the lower part of the last volution, where the surface curves toward the umbilicus.

Near the aperture the width of the upper flattened surface of the last volution is nearly 4 mm. Approximately half-way between the peripheral angle and the suture there is a prominent revolving rib, the area between this rib and the peripheral angle being distinctly concave. A similar concave area, 2 mm. in height, extends from the peripheral angle downward. Beneath this area there is a series of revolving ridges of which the upper 5 are distinct and occupy a total height of 2.3 mm. Beneath this level 4 or 5 much fainter revolving lines are seen, occupying about the same space measured along the vertical curvature of volution.

The slit-band is 0.7 mm. wide near the aperture; it is bordered by very fine, sharp lines, and its entire width is raised so as to form an angle of about 90° along the median line, the apex of this angle being rounded.

Along the flattened slope above the peripheral angle the transverse striae are very fine and curve strongly back toward the slit-band. Below the peripheral angle the transverse striae are nearly vertical, except within the groove immediately below this angle, where the striae curve distinctly back toward the slit-band.

A narrow umbilical opening remains between the inner margin of the aperture and the remainder of the lower face of the last volution.

Locality and formation.—From the argillaceous layers immediately below the Brassfield limestone at the quarry half a mile northeast of Centerville, Ohio.

Remarks.—This species is regarded as closely related to *Lophospira inexpectans* (Hall and Whitfield), but the striation of the latter is much finer and more abundant in a revolving direction.

Poleumita bellasculptilis Savage has an angular carina separating the upper slope of the volutions from their middle and basal portions. Along the last volution this upper slope is nearly flat and is marked by 3 revolving ridges of which only the middle one persists in the two uppermost volutions. Below the carina there are 12 to 15 revolving ridges. The upper volutions grad-

ually become more rounded, the more apical volutions being nearly circular in cross-section. There is some resemblance here between the mature form of *Poleumita bellasculptilis* and *Lophospira centervillensis*, but since their early stages are entirely different, according to the description presented by Salvage, it is not likely that they are related generically.

***Loxoceras husseyi* Sp. nov.**

Plate XV, figs. 3 A-D

Conch in its present condition more or less elliptical in cross-section; 15 mm. wide laterally and 11 mm. in diameter dorso-ventrally at the larger end of one fragment of a phragmacone. At the smaller end of this fragment, 30 mm. distant, the corresponding diameters are 9.5 and 8.5 mm. Originally the cross-section probably was circular, or nearly so. Apical angle usually about 10° , equalling 12° or 13° in several specimens. Nine camerae occur in this length of 30 mm. At the smaller end of the specimen there are about 3 camerae in a length equal to the lateral diameter at the top of the series being counted. Farther up this number changes to 3.7 camerae in a corresponding length.

The sutures of the septa are directly transverse. The concavity of the septa is not well shown except at the smaller ends of specimens, but it is estimated to have been about 4 or 5 mm. where the diameter is 12 to 15 mm. Location of siphuncle central, or nearly so. Segments of siphuncle oblong-elliptical, or slightly narrower below so as to be slightly fusiform in outline; 2.5 to 3 mm. wide in specimens in which these segments are 3.5 mm. in length. Septal necks short, from 0.25 to $\frac{1}{3}$ mm. in length.

Surface smooth. In a considerable number of specimens indistinguishable in any other respect from the smooth forms, the surface of the shell is covered by numerous very fine vertical striae varying from 7 to 13 in number in various individuals. Provisionally these striae are regarded as due to the structure of the interior of the shell, the striae appearing after a certain amount of weathering has taken place.

Locality and formation.—Quarry half a mile northeast of Centerville, Ohio, in the argillaceous strata immediately beneath the Brassfield limestone.

Named in honor of Dr. R. C. Hussey of Michigan University.

Spyroceras microtextile Sp. nov.

Plate XV, fig. 2

Fragments of phragmacones 8 to 9 mm. in diameter, very slowly enlarging. At present elliptical in cross-section, formerly probably circular, or nearly so. Distinctly annulated, 5 annulations occurring in a length equal to the diameter of the conch at the point where the annulations are counted. In a specimen in which the total length of one of the annulations together with that of the groove above is 2 mm., the annulation occupies a length of almost 0.8 mm., the groove being 1.2 mm. in length. The surface of the shell is ornamented by very fine vertical and transverse lines, of which the former are detected more readily. Of the vertical striae there are 12 in a width of 1 mm.; of the transverse striae there are about 10 to 12 in a length of 1 mm., their number varying apparently more than in the case of the vertical striae.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio, in the argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—Judging from the description of *Orthoceras textile* Hall, the Centerville species is closely similar in ornamentation, but the annulations are relatively more numerous. Unfortunately, the type of *Orthoceras textile* is lost, so that it is impossible to make closer comparisons.

Ctenodonta cf. simulatrix Ulrich

Plate XIV, fig. 19

Complete shells about 8 mm. in length, with outlines similar to those of *Ctenodonta simulatrix* Ulrich, from the upper part of the Richmond near Spring Valley, Minnesota. However, nothing is known of its hinge teeth.

Locality and Formation. Quarry half a mile northeast of Centerville, Ohio; in argillaceous strata immediately beneath the Brassfield limestone.

***Dalmanites* sp.**

Plate XIV, fig. 10

Fragment of the right side of a pygidium, with 9 pleural ribs, each traversed lengthwise by a median groove. For a width of about 1.5 mm. the margin of the pygidium is smooth, and unmarked by pleural ribs. The pygidium probably was 20 mm. in length, exclusive of any posterior spine, if a spine was present.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio; in argillaceous strata immediately beneath the Brassfield limestone.

Remarks.—This Centerville fragment differs from *Dalmanites danai* in having the anterior part of the pleural lobes of the pygidium more directly transverse, and the pleural ribs less strongly curved backward at mid-length of the pygidium. Moreover, the marginal part is relatively broad, flat, and free from markings by the terminations of the pleural ribs.

E. THE BRACHIOPODA OF THE BRASSFIELD LIMESTONE OF OHIO

The following is a revision of the list of brachiopoda found in the Brassfield limestone published in 1893.²⁵

- Crania dubia* Foerste
- Crania clintonensis* (Foerste)
- Plectambonites transversalis* (Wahlenberg)
- Plectambonites prolongatus* (Foerste)
- Leptaena rhomboidalis* Wilckens
- Leptaena centervillensis* Foerste. Sp. nov.
- Strophonella hanoverensis* (Foerste)
- Strophonella daytonensis* Foerste
- Schuchertella daytonensis* Foerste Sp. nov.
- Orthis euorthis* Foerste (= *militaris* Foerste)

²⁵ Foerste, A. F., Fossils of the Clinton group in Ohio and Indiana: Ohio Geol. Surv., vol. 7, 1893, p. 597.

Orthis dinorthis Foerste
Orthis fissiplicata Foerste
Hebertella fausta (Foerste)
Hebertella fausta squamosa (Foerste)
Hebertella daytonensis (Foerste)
Platystrophia daytonensis (Foerste)
Platystrophia reversata (Foerste)
Dalmanella parva (Foerste)
Dalmanella cf. *eugeniensis* Williams
Rhipidomella hybrida (Sowerby)
Triplecia ortonii Meek
Platyerella manniensis Foerste
Whitfieldella cf. *catractensis* Williams
Atrypa cf. *marginalis* (Dalman)
Atrypa marginalis multistriata Foerste
Atrypa laticorrugata Foerste
Camarotoecchia (*Stegerhynchus*) *scobina* (Meek)
Camarotoecchia convexa (Foerste)
Parastrophia sparsiplicata (Foerste)
Stricklandinia triplesiana Foerste

***Leptaena centervillensis* Sp. nov.**

Plate XIV, fig. 11

Pedical valve 30 mm. long, 28 mm. wide at mid-length, 33 mm. wide along the hinge-line, the postero-lateral angles being acute. Valve moderately convex for a distance of 25 mm. anterior to the beak, and then rapidly descending toward the anterior margin for a nearly vertical distance of 15 mm. The more moderately convex part of the valve is concentrically wrinkled as far forward as 23 mm. anterior to the beak. The number of the wrinkles varies from 11 to 16 in different specimens. The wrinkles are of approximately equal size anteriorly, becoming smaller and less elevated toward the beak. About 18 mm. anterior to the beak some specimens have a rather faint tendency toward a concentric downward curvature of the shell. The radiating striae are numerous, approximately of the same size, and number about 18 in a width of 5 mm. along the anterior slope of the shell.

The muscular scar in the interior of the pedicel valve is about 15 mm. long and 12 mm. broad. Its postero-lateral margins diverge at an angle of 80°. Along the anterior half of the scar the lateral margins are approximately parallel or converge but moderately. The lateral thirds of the anterior margin are distinctly limited, but the median third is at the level of the general surface of the interior of the valve. The lateral margins rise for a height of 0.5 mm. The adductor scars extend 12 mm. anterior to the beak, the antero-lateral parts of the muscular area extending 3 mm. farther. The total space between the valves of the complete shell at its geniculation is scarcely 5 mm.

Locality and formation.—Quarry $\frac{1}{2}$ mile northeast of Centerville, Ohio; in the upper part of the Brassfield limestone. Common.

Remarks.—Forms similar to those of typical *Leptaena rhomboidalis* are not uncommon in Brassfield strata, but the form here described is much larger, more elongate, and less abruptly geniculate anteriorly. The body of the pedicel valve is more convex, and the anterior wrinkle is not abruptly limited posteriorly.

***Strophonella hanoverensis* (Foerste)**

Strophomena hanoverensis Foerste, Proc. Boston Soc. Nat. Hist., 24, 1890, p. 301, pl. 6, fig. 1.

Strophomena (*Orthothetes*) *hanoverensis* Foerste, Geol. Surv. Ohio, 7, 1895, p. 567, pl. 27, fig. 34; pl. 31, fig. 1.

In the original description of this species it is stated that the ventral valve is convex, but that the part near the beak is flattened or even contains a very slight median depression of very short length. This depression is indicated by the upper part of the outline accompanying the figure of this supposed ventral valve. This outline is repeated in volume 7 of the Geological survey of Ohio, cited above. It is evident from this description and figure that the supposed ventral valve is in reality the brachial valve, and that the species is a true *Strophonella*.

***Strophonella daytonensis* Foerste**

Strophomena patenta Hall and Whitfield, Geol. Surv. Ohio, Pal. 2, 1875, p. 115, pl. 5, fig. 10.

Strophonella daytonensis Foerste, Amer. Jour. Sci., 4th ser., 18, 1904, p. 339.

The form figured by Hall and Whitfield is the type of *Strophonella daytonensis*. It is not uncommon in the Brassfield limestone of Ohio, and occurs also in Indiana and Kentucky. Figs. 35, 36, and 37 on plate 8 of volume 2, of the Bulletin Sci. Lab. Denison Univ., 1887, and of plate 27 of volume 7 of the Geology of Ohio, 1895, may represent young individuals of this species.

***Schuchertella daytonensis* Sp. nov.**

Streptorhynchus tenuis Foerste, Bull. Sci. Lab. Denison Univ., 2, 1887, p. 105, pl. 8, figs. 31, 32, 38.

Strophomena (*Orthothetes*) *tenuis* Foerste, Geol. Surv. Ohio, 7, 1895, p. 568, pl. 27, figs. 31, 32, 38.

Compared with typical *tenuis* (Hall), from the Waldron of Indiana, *daytonensis* is narrower and has radiating striae more nearly equal in size. Figure 32 on the plates cited above is the type.

***Orthis euorthis* Foerste**

Orthis calligramma var. *euorthis* Foerste, Geol. Surv. Ohio, 7, 1895, p. 572, pl. 25, figs. 12 a, b.

The name *euorthis* appears in the description of the plate cited above, and figure 12 on this plate represents the type of the species.

***Orthis dinorthis* Foerste**

Orthis calligramma var. *dinorthis* Foerste, Geol. Surv. Ohio, 7, 1895, p. 572, pl. 31, figs. 4, 5.

The name *dinorthis* appears in the description of the plate cited above, and figures 4 and 5 on this plate represent the types of the species.

***Orthis fissiplicata* Foerste**

Orthis calligramma fissiplicata Foerste, Geol. Surv. Ohio, 7, 1895, p. 573, pl. 37a, figs. 20, a, b.

This species is cited by Savage from the oolite member of the Edgewood limestone in eastern Missouri and western Illinois.

***Platyerella manniensis* Foerste**

Platyerella manniensis Foerste, Bull. Sci. Lab. Denison Univ., 14, 1909, p. 70, pl. 1, fig. 1A-D.

Pentamerella? *manniensis* Savage, Bull. 23, Geol. Surv. Illinois, Stratigraphy and Paleontology of the Alexandrian Series in Illinois and Missouri, pp. 28-36 of reprint.

Platyerella manniensis Foerste, Bull. Denison Univ., 19, 1920, p. 223, pl. 23, figs. 5 A-H.

This species has been found at the base of the Brassfield limestone in the quarry immediately north of Lawshe, in Adams county, Ohio. In the Alexandrian strata of Missouri and Illinois it occurs immediately beneath those strata which contain a typical Brassfield fauna. The Brassfield horizon, according to Savage, cited above, is 34 feet thick, and the underlying *Platyerella manniensis* horizon is $1\frac{1}{2}$ feet thick. *Spirifer radialis* is found in strata overlying the typical Brassfield.

In Missouri and Illinois, the *Platyerella manniensis* horizon is underlain, in descending order, by the Essex, Edgewood, and Girardeau limestones. The argillaceous strata immediately beneath the Brassfield limestone in the quarry half a mile northeast of Centerville, Ohio, appear to belong to equivalents of either the Essex or Edgewood limestone.

***Whitfieldella cf. cataractensis* Williams**

Meristella umbonata Foerste, Bull. Sci. Lab. Denison Univ., 1, 1885, p. 88, pl. 13, fig. 2 a, b; Geol. Surv. Ohio, 7, 1895, p. 590, pl. 25, fig. 2 a, b.

The Brassfield specimens described and figured under the name *Meristella umbonata* undoubtedly resemble the type of *Athyris umbonata* Billings externally. Internally they present

the structure of a *Whitfieldella*. Under the name *Hindella umbonata* Billings Hall and Clarke figure specimens from the same locality as *Athyris umbonata* Billings, but representing outlines closely similar to those of *Athyris prinstana* Billings, both of which had been described by Billings from the same locality and horizon on Anticosti island. Hall and Clarke made these supposed specimens of *Athyris umbonata* the type of their new genus *Hindella*. However, the Brassfield specimens appear to be distinct forms of *Whitfieldella*, so that, if Billings's species *Athyris umbonata* is identical with the form so recognized by Hall and Clarke, regarding which there is some possibility of doubt, then the term *Hindella umbonata* is not suitable for the Brassfield form, and the term *Whitfieldella umbonata* might prove misleading. Possibly the Brassfield species is closely related to *Whitfieldella cataractensis* Williams from the Manitoulin dolomite and Cabot Head shale of the Cataract formation of Ontario.

***Parastrophia sparsiplicata* (Foerste)**

Cyclospira ? *sparsiplicata* Sp. nov., Geol. Surv. Ohio, 7, 1895, p. 593, pl. 37a, figs. 18 a, b.

The chief feature of this shell is the presence of a median fold on the more strongly convex valve, the one whose beak overtops that of the other valve. This median fold bears two plications anteriorly, and an additional plication is faintly indicated on each side of the fold. No structure of this type exists in the genotype *Cyclospira bisulcata* (Emmons). However, in *Parastrophia* the brachial valve overtops the pedicel one. There is a tendency toward the development of a median fold with an even number of plications on this valve, and lateral plications occur. Therefore, it is regarded as much more likely that the Brassfield specimen in question belongs to the genus *Parastrophia*.

F. THE GASTEROPODA OF THE BRASSFIELD LIMESTONE OF OHIO

The following is a revision of the list of gasteropoda found in the Brassfield limestone published in 1893.²⁶

Bellerophon exiguus (Foerste)
Bellerophon opertus Foerste
Bucanella trilobata (Conrad)
Bucania fiscoelostriata (Foerste)
Oxydiscus youngi (Foerste)
Cryptaulus filitextus (Foerste) Gen. nov.
Lophospira (*Ruedemannia* ?) *inexpectans* (Hall and Whitfield)
Liospira affinis (Foerste)
Hormotoma subulata (Conrad)
Cyclonema daytonense Foerste
Cyclonema gyronemoides Foerste. Sp. nov.
Cyclora alta Foerste
Straparollus incarinatus Foerste
Diaphorostoma daytonense Foerste. Sp. nov.
Subulites directus Foerste
Meekospira planilateralis (Foerste)
Onychochilus abruptum (Foerste)

***Oxydiscus youngi* (Foerste)**

Cyrtolites Youngi Foerste, Proc. Boston Soc. Nat. Hist., 24, 1889, p. 289, pl. 6, fig. 7; Geol. Surv. Ohio, Pal. 7, 1893, p. 549, pl. 31, figs. 7, 7a.

From the cross-section of the type of the species it is evident that the last volution enveloped the carina of the preceding volution with a heart-shaped base, as in typical *Oxydiscus*, the conch being narrow and the carina very acute.

***Cryptaulus* Gen. Nov.**

Spire low, the successive volutions rising high up on the sides of the immediately preceding volutions, and covering the slit-band of the latter entirely. The upper part of each volution

²⁶ Foerste, A. F., Fossils of the Clinton group in Ohio and Indiana: Ohio Geol. Surv., vol. 7, 1893, p. 596.

is less convex than its sides, thus assisting in the general depressed appearance of the spire. Along mid-height of the last volution is a narrow slit-band, bordered on each side by a single striation, which is distinct, though but slightly raised above the general surface of the shell. General vertical outline of the volutions rounded, without revolving ridges, striae, or grooves, excepting only the groove of the slit-band. All surface striae transverse. Umbilicus open, as far as known.

Genotype.—*Pleurotomaria filitexta* Foerste.

***Cryptaulus filitextus* (Foerste)**

Pleurotomaria filitexta Foerste, Geol. Surv. Ohio, Pal. VII, 1893, p. 550, pl. 37A, figs. 6a, b.

Shell 10 mm. wide, and scarcely 6 mm. high. Volutions 5, the spire rising 1.7 mm. above the surface of the last volution. Slit-band barely 0.4 mm. in width near the aperture. Here 22 transverse striae occur in a width of 2 mm. These striae curve backward along the upper surface of the last volution so as to form an angle of about 70 degrees with the slit-band until within the immediate vicinity of the latter, where the transverse striae curve more strongly backward. Along the lower side of the slit-band the transverse striae also curve backward on approaching this band.

Locality and formation.—Found at the abandoned Huffman quarry $\frac{3}{4}$ mile southeast of the Asylum for the Insane, in the southeastern part of Dayton, Ohio, in the Brassfield limestone.

Remarks.—The general appearance of *Cryptaulus filitextus* is that of a *Helix*, but provided with a slit-band at mid-height of the last volution, the slit-band of earlier volutions being covered up successively by the later volutions. No other Silurian shell with exactly the same type of structure is known.

Pleurotomaria aequilatera (Wahlenberg), as figured by Lindström²⁷ is similar in its general *Helix*-like form, its open umbilicus, and the presence of a slit-band at mid-height, or only slightly above mid-height of the volutions. Figure 27 on the plate cited

²⁷ Lindström, Silurian Gastropoda of Gotland, 1881, pl. 9.

bears the greatest resemblance, but in all cases the slit-band remains exposed, immediately above the sutures.

Pleurotomaria helicina Lindström,²⁸ is similar in having the slit-band of earlier volutions covered up by the successively later volutions, but the slit-band is located slightly above mid-height of the volutions and there is a revolving callous thickening along the rim of the umbilicus. The shell is much more depressed. Possibly this species may prove congeneric with *Cryptaulus filitextus*.

In the genus *Trepostira* Ulrich²⁹ the slit-band also is visible only on the last volution, but the umbilicus is closed by a callous deposit. Shells of this type originated apparently as early as the Hamilton formation, where *Pleurotomaria rothalia* occurs. However, the typical forms of this genus are of Carboniferous age.

Lophospira (Ruedemannia?) inexpectans (Hall and Whitfield)

Pleurotomaria inexpectans Hall and Whitfield, Geol. Surv. Ohio, Pal. 2, 1875, p. 117, pl. 5, fig. 12.

Height 26.5 mm., greatest lateral diameter 23.5 mm., greatest height of spire 16.5 mm., apical angle 83°. Slit-band peripheral, 1.5 mm. in width near the aperture, distinctly outlined along its upper and lower margins by sharply defined revolving striations. Slit-band strongly convex transversely, its median parts rising at least $\frac{1}{3}$ mm. above its lateral parts toward the aperture. Here, where its width is 1.5 mm., the median part of the slit-band is traversed by three revolving striae, equally spaced, 0.3 mm. apart. Of these the middle striation is traversed longitudinally by an extremely narrow groove, which can be detected only where the preservation of the shell is excellent. Along the periphery of the second-last volution, the slit-band is acutely angular instead of convex, and there is only a single revolving striation, but this is prominent and is located along the median line of the band.

²⁸ Lindström, Idem., pl. 11.

²⁹ Ulrich, E. O., and Scofield, W. H., The Lower Silurian Gastropoda of Minnesota: Minn. Geol. and Nat. Hist. Surv., Pal. vol. 3, pt. 2, 1897, p. 957.

In the last volution, the vertical outline above the slit-band is gently concave, the concave curvature being more pronounced toward the band. Below the slit-band the vertical outline is convex, with a tendency toward a concave outline within 2 mm. of the band, due chiefly to the prominence of the peripheral portion of the shell bearing this band. In the second-last volution, the slope of the shell above the slit-band is interrupted at mid-height by a very prominent revolving striation, dividing this slope into two equally concave revolving areas. Along the last volution this striation becomes less prominent and occupies a position increasingly farther up the slope, being three-fifths of the distance from the slit-band to the suture above, near the aperture. Along this part of the shell the striation in question is merely slightly more prominent than those above and below, and does not interrupt conspicuously the general concave outline between the slit-band and the suture above. Above this more prominent striation, the surface of the last volution is marked by 9 revolving striae. Beneath this more prominent striation there are 4 striae about as prominent as those above this striation, and then a fifth striation distinctly more prominent than any of the preceding four is found. The upper half of the space between the fifth striation and the slit-band is occupied by 5 much fainter striae, with a sixth faintly visible a short distance beneath. Along the second-last volution only 4 or 5 revolving striae occupy each of the two concave areas forming the visible part of this volution between the slit-band and the suture above.

Immediately below the slit-band, along the concave part of the shell, toward its aperture, the revolving striae are very faint toward the band but become increasingly stronger at a greater distance. At least 40 revolving striae occur between the slit-band and the umbilical portion of the shell. These tend to be approximately equal in size, though slight alternation in prominence is noted. In general the prominence of these striae distinctly exceeds that of most of the striae along the upper two-thirds of that part of the last volution which is above the slit-band.

Transverse or vertical striae distinct, sharply defined, and equidistant. Along the peripheral part of the last volution, near the aperture, 8 striae occur in a width of 2 mm. Three millimeters below the slit-band, the number of transverse striae increases abruptly from 8 to 13 in a width of 2 mm., and this finer striation continues as far as the umbilicus.

Along the slit-band the transverse striae curve backward so as to form an angle of 60° with the vertical axis; farther up they form an angle of 80° with this axis, and farther down their direction is at first vertical, with a backward curve on approaching the umbilical parts of the shell.

Locality and Formation.—Near the Whippoorwill school, $3\frac{1}{2}$ miles northeast of West Union, in the oolitic iron ore at the top of the Brassfield formation.

Type.—The type specimen, used for the original description, was found in the oolitic iron ore at the top of the Brassfield limestone, on Todd Fork, nearly 3 miles north of the center of Wilmington, in Clinton county, Ohio.

Remarks.—This species is characterized by the prominent elevation of the median part of the slit-band. In this respect it resembles typical *Lophospira*. It appears to have originated from a shell similar to *Lophospira lirata* Ulrich, from the Economy and Southgate members of the Eden formation in the vicinity of Cincinnati, Ohio. It resembles the latter in the division of the slope above the slit-band into two revolving concave areas, and in the tendency toward a faint concave area immediately beneath this slit-band; it is similar also in possessing revolving striae along the lower part of the last volution. It is dissimilar in having these revolving striae much more sharply defined, much more numerous and present above as well as below the slit-band.

It would have been far better if *Pleurotomaria inexpectans*, instead of *Lophospira lirata* had been selected as a type of *Ruedemannia*, since it appears to be along this direction that *Lophospira lirata* seems to have varied.

Pleurotomaria robusta Lindström is similar to *Lophospira lirata*, in the features mentioned above.

In *Pleurotomaria scutulata* Lindström and *P. gradata* Lindström the median part of the slit-band is occupied not by a single striation but by two, a feature throwing these shells out of alignment with *Lophospira*. In a similar manner the concave slit-bands of *Clathrospira*, *Plethospira*, and *Seelya* throw these genera out of alignment with *Lophospira* and its subdivision *Ruedemannia*.

Cyclonema daytonense Foerste

Cyclonema bilix Foerste, Proc Boston Soc. Nat. Hist. 24, 1889, p. 290, pl. 5, fig. 15; Geol. Surv. Ohio, Pal., 7, 1893 p. 551, pl. 30, fig. 15.

Cyclonema daytonensis Foerste, 24th Ann. Rep. Indiana Geol. Nat. Hist. Surv., 1899, p. 77; Journ. Geol., 11, 1903, p. 707.

Cf. *Cyclonema bilix* Conrad, Jour. Acad. Nat. Sci. Philadelphia, 8, 1842, p. 271, pl. 16, fig. 10.

The type of *Cyclonema daytonense* is the specimen figured from Brown's quarry, near New Carlisle, Ohio, in 1889, and again in 1893, in the reports cited above. This species is widely dispersed, and is one of the most common gasteropoda found in the Brassfield formation in Ohio, Indiana, and Kentucky. In the Brassfield limestone of western Tennessee it is found as far south as Clifton, on the Tennessee river, and it has been cited from Thebes, Illinois, and Edgewood, Missouri, from the Edgewood formation.

The species *C. bilix* was described from Richmond, Indiana, where only the Elkhorn, Whitewater, and Liberty members of the Richmond, in descending order, are exposed. The Brassfield limestone is well exposed at the falls on Elkhorn creek, 3 miles southeast of Richmond.

The forms of *Cyclonema* found in the Whitewater and Liberty members are usually erect and relatively tall. *Cyclonema bilix conica* Miller³⁰ is the extreme form of this group. It has been

³⁰ Miller, S. A., The position of the Cincinnati group in the geological column of fossiliferous rocks of North America: Cincinnati Quart. Jour. Sci., vol. 1, 1874, p. 320.

well illustrated by Meek³¹ and Ulrich.³² In the Waynesville member of the Richmond the forms are relatively broader.³³ In the Arnheim, and in the lower part of the Waynesville members, there is a form known as *Cyclonema fluctuatum* James³⁴ which is not only broad, but which tends to be wrinkled transversely and to be depressed along the upper third of the lower volutions.

None of these Richmond forms resembles the figure of *Cyclonema bilix* published by Conrad. The latter is not a strongly erect, conical form, but, on the contrary is low and apparently with a strongly oblique axis. Shells of this type are relatively common in the Brassfield limestone, 3 miles southeast of Richmond, while not known in the Elkhorn, Whitewater, or Liberty members of the Richmond at any locality near Richmond, Indiana.

The locality and formation assigned by Conrad to his *Cyclonema bilix* was Richmond, Indiana, in limestones of the age of the Salmon river series of New York. Conrad included in his Salmon river series not only strata now known as Lorraine but also the unfossiliferous sandstone which caps the Lorraine at the Falls of the Salmon River. This accounts for his use of the term Salmon River sandstone in his various reports, although some of the underlying beds contain relatively thin sandstone layers also. It is possible that the falls of the Elkhorn were included in the Salmon River series by Conrad, and that the type of his *Cyclonema bilix* was not a Richmond, but a Brassfield form.

No good purpose, however, would be served by resurrecting the name *Cyclonema bilix* for the Brassfield, instead of the Richmond species. The mere fact that no element of certainty attaches to its stratigraphic origin suggests that either this name

³¹ Meek, F. B., Fossils of the Cincinnati Group: Paleontology of Ohio, vol. I, 1873, pl. 13, fig. 5 g.

³² Ulrich, E. O., and Scofield, W. H., The Lower Silurian Gastropoda of Minnesota: Minn. Geol. and Nat. Hist. Surv., vol. 3, 1897, pl. 78, figs. 38-39.

³³ Idem: pl. 78, figs. 35, 36, 37.

³⁴ Idem: pl. 78, figs. 40, 41, 42.

should be dropped, or that Ulrich should be followed in his definite choice of a type or of a series of types from a definitely known horizon. Ulrich's three specimens of *Cyclonema bilix*³⁵ figured first under that name in the Paleontology of Minnesota, from Versailles, Indiana, and Waynesville and Clarksville, Ohio, are definitely of Richmond age, and their horizon probably was that of its Waynesville member.

***Cyclonema gyronemoides* Sp. nov.**

Cyclonema bilix varicosum Foerste, Geol. Surv. Ohio, Pal., 7, 1893, p. 552, pl. 37A, fig. 9.

Shell with 3 or 4 volutions, rapidly enlarging, the last volution forming by far the greater part of the shell. In most of the specimens at hand the spire appears somewhat depressed, similar to the spire of *Cyclonema daytonensis* as figured in 1893.³⁶ Along the middle and upper thirds of the last volution the shell is ornamented by strong revolving ridges, usually 5 in number; revolving striae also are present, but usually these are faint, are close together, and occur on the ridges as well as on intermediate parts of the shell. Along the upper half of the lower third of the last volution there are additional faint revolving striae; along the lower half of this third, only the transverse striae usually are present.

The third revolving ridge from the top of the last volution usually is located slightly above mid-height of this volution, and the other two ridges are so placed between the third volution and the suture above that the width of the intermediate concave spaces decreases only moderately in ascending order. The fourth revolving ridge occurs at an interval considerably shorter than that above the third ridge, and is distinctly less conspicuous. The fifth revolving ridge occurs at a shorter interval than any of the preceding ridges, and is distinctly less conspicuous than the fourth ridge.

³⁵ Idem: pl. 78, figs. 35, 36, 37.

³⁶ Foerste, A. F., Fossils of the Clinton Group in Ohio and Indiana: Geol. Surv. Ohio, Pal. vol. 7, 1893, pl. 30, fig. 15.

The transverse striae are much finer and more crowded than those of *Cyclonema daytonense* Foerste,³⁷ from the same horizon and general area. Near mid-height of the last volution these striae form an angle of about 30° or 35° with the vertical axis of the shell.

Locality and formation.—Found at Todd Fork, north of Wilmington, Centerville, Dayton, Sharpsville, and east of Danville, Ohio, in the Brassfield formation.

Remarks.—The only published figure of *Cyclonema gyronemoides* is that found in volume 7 of the Geological Survey of Ohio, on plate 37A, under the name *Cyclonema bilix varicosum*. This figure was based on a series of fragments of which the largest and most important consisted chiefly of the upper part of the last whorl, including the 5 prominent revolving ridges. The basal part of the last volution and the aperture were added from other specimens. This aperture evidently is that of a *Cyclonema*, and it remains to be shown that the species here described as *Cyclonema gyronemoides* possessed this type of aperture. At the time the figure was prepared numerous specimens of this species were at hand. Those recently collected do not show the aperture. In the published figure the spire appears to be much taller than in the specimens now at hand, possibly owing to the specimen being viewed from its narrowest aspect. However, here, again, there is a possibility of the apical part of the figure having been derived from some other specimen. In the specimens now at hand the spire is relatively depressed, somewhat as in the figure of *Cyclonema daytonense* published on plate 30 of the volume cited above, under the name *Cyclonema bilix*. Under these circumstances only the upper part of the last volution of figure 9 on plate 37A of the volume cited is to be regarded as unequivocally typical of the species *Cyclonema gyronemoides*; this part includes the 5 prominent revolving ridges. The remainder of the figure may be correct, but the specimens from which it was prepared have been lost, so that the accuracy of the remainder of this composite drawing can not be verified.

³⁷ Idem: pl. 30, fig. 15.

While not common, as in case of *Cyclonema daytonense*, specimens of *Cyclonema gyronemoides* are widely distributed in the Brassfield of Ohio, and form one of its characteristic species. Apparently the latter is not a species of *Gyronema*. In that genus there is a distinct umbilicus, though small, and the inner margin of the aperture is not reflexed so as to cover this umbilicus.

***Diaphorostoma clintonense* (Foerste)**

Platyceras Niagarensis var. Clintonense Foerste, Geol. Surv. Ohio, Pal. 7, 1893, p. 554, pl. 37a, fig. 8.

The type of this species was a specimen with a very low, closely coiled spire, but with the last half of the last volution curving strongly downward. It was found in the ferruginous limestone at the top of the Clinton, just under the Onondaga shales, near Mifflintown, in Juniata county, Pennsylvania.

***Diaphorostoma daytonense* Sp. nov.**

Platyostoma Niagarensis Foerste, Bull. Sci. Lab. Denison Univ., 1, 1885, p. 97, pl. 13, figs. 3 a; fig. 22 a, b.

Platyceras (Platyostoma) Niagarensis Foerste; Geol. Surv. Ohio, Pal. 7, 1893, p. 553, pl. 25, figs. 3 a; figs. 22 a, b.

The Brassfield form differs from the typical Rochester shale form of *Diaphorostoma niagarensis* (Hall) in possessing a lower spire, the height of the body whorl is greater, and there is less tendency toward the production of broad revolving ridges and grooves; it does not attain as large a size, and the transverse striae are finer. Only gerontic forms present the large apertures represented by figure 22 in the plates cited above. Most specimens resemble figure 32 on these plates, but with about 2 mm. added to the lateral extent of the last volution. Specimens resembling figure 3b on these plates are very rare, and represent merely aberrant individuals. For these Brassfield forms the name *Diaphorostoma daytonense* is proposed.

***Onychochilus abruptum* (Foerste)**

Paleopupa abrupta Foerste, Geol. Surv. Ohio, Pal., 7, 1893, p. 556, pl. 37A, fig. 21 a, b.

The genus *Onychochilus* was proposed by Lindström in 1881, in his Silurian Gasteropoda of Gotland, three species, *Onychochilus physa*, *On. reticulatum*, and *On. cochleatum* being described by him in the order named, the latter doubtfully referred to the genus. Of these the first named, *Onychochilus physa*, here is regarded as the type.

The specific name *physa* indicates the sinistral curvature of the spire of the type species, a feature shared by all three species described by Lindström, and also by the peculiar gasteropod described by me under the generic term *Paleopupa*. The choice of the name *Paleopupa* as a generic term for a sinistral shell is unfortunate, since the Brassfield species so designated could not have been ancestral to any form of *Pupa*. Its resemblance to *Pupa* ends with its rapid apical expansion, followed by a much slower expansion along the last volution. Nothing is known of its surface ornamentation.

In *Onychochilus physa* the aperture is obliquely rounded, the lower margin being distinctly angulated. There is no trace of an umbilicus. The surface striation is transverse. In *Onychochilus reticulatum* the angulation at the base of the aperture is even more pronounced. Vertical sections show that the umbilical passage through the axial part of the shell has been closed by a callous deposit. The surface is ornamented by both transverse and revolving striae, readily seen under a lens. In both species the rate of increase in size is more even than in *Paleopupa abrupta*, and in the latter species no angulation of the base of the aperture was noted, but this part was not well preserved in the specimens studied.

Nothing appears to be known of the relationship of *Onychochilus*, and the term does not appear in Zittel-Eastman's Textbook of Paleontology.

G. NIAGARAN FOSSILS FROM JEPHTHA KNOB, KENTUCKY

Jeptha Knob is a conspicuous elevation of land 6 miles south-east of Shelbyville, in Shelby county, Kentucky. The knob attains an elevation of about 1300 feet above sea level. Its upper levels consist of Richmond strata, but on its upper parts are found also residual fragments of Silurian strata, showing that it had once been overlain by the latter. Among the latter may be recognized a few fragments of crystalline limestone, which both lithologically and paleontologically can be identified as of Brassfield age. Most of the Silurian fragments however consist of flat pieces of chert. These pieces of chert evidently were derived from chert layers interbedded in some limestone formation. Since in the counties directly west of Shelby county, including Oldham and Jefferson counties, it is the Laurel member of the Niagaran which contains flat layers of chert in abundance, these Silurian chert fragments on Jeptha Knob are interpreted as also of Laurel age.

Both Prof. Arthur M. Miller of the University of Kentucky, and Prof. Walter H. Bucher of Cincinnati University have been very active in securing fossiliferous fragments of this Laurel chert, and both have secured fragments of a large species of *Calymene*, similar to *Calymene cedarvillensis* Foerste, but possibly belonging to a distinct species. The fauna includes

- Favosites favosus (Goldfuss)
- Lyellia thebesensis Foerste
- Pachydictya cf. bifurcata (Hall)
- Dalmanella sp., with fine radiating plications
- Dalmanella sp., with very coarse plications
- Rhipidomella hybrida (Sowerby)
- Platystrophia daytonensis (Foerste). (Plate XV A, fig. 11.)
- Schuchertella sp. (Plate XV A, fig. 12.)
- Strophonella milleri Sp. nov.
- Camartoechia indianensis (Hall). (Plate XV A, figs. 10 A, B.)
- Cypricardinia jepthaensis Sp. nov.
- Hormotoma sublaxa (Conrad)
- Lophospira bucheri Sp. nov.

Trochonema sp., resembling *Trochonema beloitense* Whitfield in having two lateral revolving ridges, and one ridge near the upper suture, but entire height of shell only 10 mm., and with more acute apical angle. (Plate XV A, fig. 7.)

Calymene cf. *cedarvillensis* Foerste

Iliaenus daytonensis Hall and Whitfield. (Plate XV A, fig. 13)

***Lyellia* cf. *thebesensis* Foerste**

Plate XV, fig. 8

Lyellia thebesensis Foerste, Bull. Sci. Lab. Denison Univ., 14, 1909, p. 95, pl. 4, fig. 69.

Corallum 70 mm. in width and 45 mm. in height; maximum size unknown. Corallites averaging 1.5 mm. in diameter, the distances between the corallites averaging between 0.4 and 0.5 mm., two and a half to three corallites occurring in a length of 5 mm. The corallites are tubular in form and are crossed by 8 to 13 tabulae in a length of 5 mm. The spaces between the corallites are crossed by vesicular tissue, the plates of which sometimes are not much closer together than the tabulae within the corallites. When the corallum is viewed from above, this vesicular tissue frequently has a more or less radiating appearance.

Locality and formation.—In the loose chert, assumed to be of Laurel age, on Jephtha Knob, Kentucky.

***Strophonella milleri* Sp. nov.**

Plate XIV, fig. 9

Pedicle valve 17.5 mm. long, 23.5 mm. wide at the hinge-line, with the lateral sides converging at an angle of about 36° from the postero-lateral angles toward the antero-lateral ones, and then rounding anteriorly, with a tendency toward angulation in front, somewhat as in *Strophonella costulata* Hall and Clarke. For a distance of 3 to 5 mm. from the beak the valve is distinctly convex, but 8 mm. from the beak the curvature reverses to concave and remains so as far as the margin of the valve. There is a tendency toward depression also along the median line of

the valve along its anterior part, as in the species mentioned above. The radiating striae, however, are much more numerous, numbering 6 to 8 in a width of 3 mm.

Locality and formation.—In the loose chert, assumed to be of Laurel age, on Jephtha Knob, Kentucky.

***Cypricardinia jephthaensis* Sp. nov.**

Plate XV A, fig. 6

Right valve 18.5 mm. long, 9.5 mm. high, and 3 mm. deep. Umbo broad and rounded, near the anterior end of the shell. The latter extends only about 2 mm. beyond the beak, there being a faint concave outline between this anterior end and the beak. The general outline of the shell is transversely elliptical, highest at the beak and narrowing but moderately posteriorly. The posterior border is more narrowly rounded than the anterior one. The greatest depth of the valve is at mid-length. There is a slight tendency toward flattening in the umbonal area. The umbonal ridge is weakly defined and lies near the upper margin of the valve. Growth lines are indicated in directions similar to those of *Cypricardinia arata*, but so faint as to be almost imperceptible. Compared with the Racine species, the Jephtha Knob form is more elongate, and its posterior portion is less elevated; moreover, the umbonal part is broader and flatter.

Locality and formation.—From the loose chert, assumed to be of Laurel age, on Jephtha Knob, Kentucky.

***Lophospira bucheri* Sp. nov.**

Plate XV A, fig. 9

Shell 40 mm. in height, 32 mm. in maximum width, with a vertical height of 22 mm. at the aperture, and an apical angle of 60°. There are 6 or 7 volutions. Along the last half of the last volution there is a salient peripheral angle extending about 1.5 mm. beyond the general convexity of this part of the shell. Along the corresponding part of the preceding volution the peripheral angle is sharply angular but not salient. Here the upper part of the last volution conceals the lower part of the preceding

volution to a level 4 mm. beneath the peripheral angle of the latter, and corresponding concealment is shown along the upper volutions. Directly over the aperture, the second last volution shows a prominent revolving striation two-fifths of the distance from the suture above to the peripheral angle beneath, along the upper face of the volution. Above and below this revolving striation the upper face of the volution is gently concave. No trace of this revolving striation can be detected along the last half of the last volution. The character of the slit-band on the peripheral angle can not be determined beyond the fact that it is not broad and deep as in *Phanerotrema*. On the last volution fine striae curve backward from the suture above toward the peripheral angle, and on the lower side of this angle they curve at first moderately forward, then vertically downward, and finally moderately backward toward the umbilicus. Apparently there are traces of numerous fine revolving striae, but these traces are so vague that the presence of such revolving striae can not be asserted with confidence. Possibly the shell is related to the group typified by *Lophospira inexpectans*, but in that case the trilineate character of the slit-band should be in evidence, even in a shell whose surface is no better preserved than the one at hand.

Locality and formation.—In the loose chert, assumed to be of Laurel age, on Jeptha Knob, Kentucky. Named in honor of Prof. Walter H. Bucher, of the University of Cincinnati.

***Calymene cf. cedarvillensis* Foerste**

Plate XIII, figs. 10 A, B, C

Calymene cedarvillensis Foerste, Bull. Sci. Lab. Denison Univ., 19, 1919, p. 78, pl. 18, figs. 11 A, B, C.

Fragments of the cranidium, thorax, and pygidium indicate the presence of a large species of *Calymene*, certainly equalling 160 mm. and probably equalling 170 mm. in length. It is easily comparable in size, therefore, with the large specimens of *Calymene platys* Green from the Schoharie grit of New York.

Compared with *Calymene cedarvillensis* from the Cedarville dolomite at Cedarville, Ohio, the anterior border of the cranidium and the groove intervening between this border and the anterior margin of the glabella appears relatively broader, from front to rear, in the Jephtha Knob specimens.

Compared with *Calymene vogdesi* Foerste, from the Brassfield limestone of southwestern Ohio, the posterior margin of the pygidium is more strongly curved; the median axis of the pygidium is relatively broader, and the lateral parts are correspondingly narrower in the Jephtha Knob specimens. The median groove on the pleural ribs of the pygidium are distinctly defined only along the more distal parts of these ribs.

Undoubtedly other distinguishing features would be noted if better specimens of the Jephtha Knob, Cedarville, and Brassfield species were at hand.

***Orthis bucheri* Sp. nov.**

Plate XV A, fig. 14

Brachial valve 26 mm. long, estimated to have been 32 mm. wide; nearly flat, with a shallow median depression. With 17 or 18 primary radiating plications, alternating with which there is a secondary series, not reaching the beak. Both primary and secondary plications tend to be rather angular along their crests, and not flattened as in typical *Orthis*. The structure of the shell is strongly fibrous.

Locality and formation.—South spur of South Hill on Jephtha Knob, Kentucky; at the base of the crinoidal Brassfield limestone. Collected by Prof. Walter H. Bucher, in whose honor the species is named.

H. TRILOBITES FROM THE ST. CLAIR LIMESTONE OF ARKANSAS

Among the trilobites studied by Prof. Gilbert Van Ingen³⁸ from the St. Clair limestone at Batesville, Arkansas, the following never were described or figured: *Calymene altirostris*, *Cyphaspis*

³⁸ Van Ingen, Gilbert, The Silurian Fauna near Batesville, Arkansas, I: School of Mines Quart., vol. 23, 1901, p. 35.

arkansana, and *Cyphaspis spinulocervix*. Prof. Van Ingen has very kindly loaned the types of these species to the writer for description, and in these descriptions the names proposed by Prof. Van Ingen have been retained. The collection loaned by Prof. Van Ingen includes also several specimens of a new species of *Proetus*, which I take pleasure in naming after him.

***Calymene altirostris* Sp. nov.**

Plate XIV, figs. 1 A, B, C

Two cranidia are at hand which may not belong to the same species. The one in which the anterior or rostral border is most conspicuously elevated undoubtedly is the specimen which suggested the name *altirostris*, and must serve as the type of the species, although it is an inferior specimen otherwise.

Length of cranidium, including the anterior border and the glabella, but lacking the neck-ring, 5.5 mm. Including the neck-ring its original length may have been nearly 6.5 mm. The glabella alone is nearly 4 mm. in length, and its maximum width at the base is estimated at 4.2 mm. The anterior margins of the lateral lobes are approximately 1.5, 2.5, and 3 mm. from the posterior margin of the posterior pair of lobes. The anterior pair is but faintly indicated, while the other two pairs of lobes and the median part of the glabella are strongly convex. The general elevation of the anterior part of the glabella above the lateral parts of the cranidium is about 1.4 mm., and the anterior or rostral border rises nearly 1 mm. above the general antero-posterior curvature of the median part of the glabella. Viewed from in front, the doublure of the rostral part has an elevation of 1.2 mm., and its face rises at an angle of 95° with the general horizontal plane of the cranidium, inclining slightly forward from the vertical. The deep groove between the anterior border and the glabella is scarcely a third of a millimeter in width. The anterior margin of the glabella tends to be squarish. The surface of the cranidium is covered by minute granules, visible only under a lens.

The second specimen belonging to the type series of this species is much better preserved. Including the neck-ring, the cranidium is 5.2 mm. in length. The anterior margin of the anterior border extends 1.3 mm. in front of the glabella, the groove between this border and the glabella being 0.25 mm. The glabella tends to be more narrowly rounded anteriorly, and the anterior or rostral border also appears more narrowly rounded. This rostral border is strongly elevated anteriorly, but its upper margin does not rise above the general curvature of the glabella antero-posteriorly.

Notwithstanding the differences noted, the two individuals probably belong to the same species.

Calymene sp.

Plate XIV, figs. 2 A, B, C.

Four pygidia of the same general appearance are mounted on the same small card, and a fifth specimen, loose, was used for a lateral view. The largest of these originally was 4.8 mm. in length, 7.8 mm. in width, and had a convexity of slightly over 2 mm. anteriorly. The axial lobe is 3 mm. in width anteriorly and rises 0.8 mm. above the adjacent parts of the lateral lobes. The outer part of the lateral lobes curves downward toward the margin of the pygidium, but without any reversal of curvature on approaching the latter. The downward curvature begins along a line corresponding to that described in the case of *Cyphaspis arkansana*, but the downward curvature along this line is less abrupt.

The axial lobe bears 2 distinct rings, anteriorly, behind which there is one ring which is fairly distinct and another ring which is faintly visible; 1 or 2 additional rings may be barely perceptible, and 1 specimen shows a seventh ring. The pleural ribs on the lateral lobes usually are indistinctly marked, except the anterior 2 or 3 pairs, these anterior ribs being grooved along their median lines.

It is the absence of any trace of outward curvature along the margin of the pygidium, and the presence of additional discern-

ible rings on the axial lobe which distinguish the pygidia here described under the name *Calymene* from those referred by Prof. Van Ingen to *Cyphaspis arkansana*.

***Proetus vaningeni* Sp. nov.**

Plate XIV, figs. 3 A, B, C

Five cranidia are at hand, of which the largest has a length of 5.8 mm. The glabella is 4.7 mm. long, the anterior border of the cranidium is 1.1 mm. long, and the neck-ring is 1 mm. in length. The maximum width of the glabella at its posterior end is 3.9 mm. The glabella is strongly convex, both laterally and antero-posteriorly. In the latter direction its greatest convexity is about one-third of the length of the glabella from its anterior margin. Here the convexity of the glabella is fully 1 mm. Along the posterior two-thirds of the glabella its antero-posterior curvature is distinctly less in an antero-posterior direction, though still fairly strong laterally. No trace of a posterior pair of lobes was detected, though the glabella widens slightly here. In general, the sides of the glabella are nearly parallel, converging slightly toward the front until the inward curvature of the facial sutures in front of the palpebral lobes is reached, but anterior to the latter the sides curve with increasing rapidity and the anterior margin of the glabella is evenly rounded. Along the anterior part of the glabella the antero-posterior curvature of the glabella is so strong that this part of the glabella tends to arch forward over the groove limiting its anterior margin. No area intervenes between the anterior margin of the glabella and the median part of the anterior border of the cranidium for a width of a millimeter and a half. The upper surface of this border is flattish or gently convex, and inclines upward and forward at an angle of about 160° with the general horizontal plane of the cranidium. The neck furrow is deep. The neck-ring is unarmed with any median tubercle as far as known. The palpebral lobes are 0.75 mm. in width, and their anterior margin extends 2.4 mm. in front of the rear margin of the glabella. The surface of the cranidium is almost smooth, even under a lens.

One of the small cranidia is 4 mm. in length, but it is well preserved.

***Cyphaspis spinulocervix* Sp. nov.**

Plate XIV, figs. 4 A, B, C

Three specimens belong to the type series. Of these only one presents the long nuchal spine, and this specimen must, therefore, be considered the type.

Glabella 1.5 mm. in length; 0.75 mm. in width posteriorly, including the lateral lobes, 0.8 mm. in width along the neck furrow, excluding these lobes. The lobes are 0.6 mm. in length. The width of the neck-ring is 0.2 mm., and the nuchal spine extends 1.8 mm. beyond the posterior margin of this ring. The spine is long and narrow and starts off abruptly from the posterior margin of the ring. The glabella is strongly convex, and only the posterior margin of the area intervening between the glabella and the anterior border of the cranidium is shown.

The second specimen retains only the point of attachment for the nuchal spine, but the spine itself is missing. The remainder of the specimen, however, is well shown. The length of the cranidium is 4.1 mm. Of this length 2.5 mm. belongs to the glabella, 0.4 mm. to the neck-ring, and 1.2 mm. to that part of the cranidium which is in front of the glabella. The width of the glabella including the lateral lobes is almost 3 mm.; excluding these lobes its width posteriorly is 1.4 mm. The length of the lobes is 0.9 mm. Their form is ovate. The space between the anterior margin of the glabella and the anterior border of the cranidium is 0.8 mm. in length, 0.4 mm. being occupied by the anterior border. A narrow, deeply impressed groove borders the anterior and antero-lateral parts of the glabella. Immediately anterior to this groove the cranidium is distinctly convex antero-posteriorly. A similar narrow groove borders the posterior margin of the anterior border of the cranidium. This border inclines upward and forward at an angle of about 135° with the general horizontal plane of the cranidium. The glabella, its lobes, and the area intervening between the glabella and the anterior border of the cranidium are relatively coarsely

granulated, considering the small size of the specimen, 5 to 6 granules occurring in a distance of 1 mm. Along the neck-ring and fixed cheeks the granules are less prominent, and along the anterior border of the cranidium they can be detected with difficulty.

The third specimen belonging to the type series does not add to the information given by the preceding specimens.

***Cyphaspis arkansana* Sp. nov.**

Plate XIV, figs 5 A, B, C

Four pygidia are present in the type series, and of these the largest is 3.6 mm. in length, 5.6 mm. in width, and about 2 mm. in maximum convexity anteriorly. The axial lobe originally was 2.5 mm. in width anteriorly; at present only the cast of the lower surface of the pygidium remains. Originally this axial lobe rose strongly above the adjacent parts of the lateral lobes; possibly 1 mm. The greater part of the lateral lobes curves strongly downward toward the lateral margins of the pygidium, the downward curvature beginning along a line extending from a point 0.8 mm. from the anterior end of the lateral margin of the axial lobe diagonally backward and inward, so as to continue around the posterior margin of the axial lobe in a U-shaped direction. Parallel to the posterior and lateral margins of the pygidium, along a line passing immediately posterior to the axial lobe, there is a faint tendency toward an outward or concave curvature, visible only under favorable illumination. It may be this faint outward curvature along the margin which suggested the reference of these pygidia to *Cyphaspis*, rather than to *Calymene*.

The axial lobe bears 2 distinct rings with indistinct indications of a third ring. Posterior to these there is room enough for 3 additional rings, but the surface of the axial lobe here usually is smooth. The pleural ribs are weakly indicated. The anterior pair show median grooves. The third pair is too faintly indicated to give evidence of grooving. Nothing can be identified distinctly farther back.

No glabellae accompany these pygidia belonging to the type series. I am unable to discriminate between the glabellae of *Cyphaspis*, *Proetus*, and *Calymene* in specimens of such small size, but regard *Cyphaspis* as a possibility in the case of the pygidia here described.

I. A NEW GASTEROPOD FROM THE GUELPH FORMATION OF OHIO

Straparollus paveyi Sp. nov.

Plate XV, figs. 1 A, B, C

Shell strongly depressed; greatest lateral diameter 63 mm.; height 37 mm. The spire rises about 20 mm. above the last volution at its aperture. Volutions at least 5, possibly 6. The suture between the last volution and that immediately preceding is about two-fifths of the height of the latter above its base. From this suture downward for a short distance the upper part of the inner outline of the cross-section of the last volution is distinctly though moderately concave. Along the remainder of its contour this outline is approximately circular, but slightly depressed vertically, and with a tendency toward oblique flattening of that part of its slope which is immediately above mid-height of the last volution. Near the aperture, the lateral diameter of the last volution is 23.5 mm., and its vertical diameter is 22 mm. The oblique flattening above mid-height forms an angle of about 30° with the vertical axis of the shell. The umbilicus is wide and open, showing all of the volutions; its greatest diameter in the specimen here described is 20 mm.

Owing to the oblique flattening of that part of the last volution which is immediately above mid-height there is a tendency toward a shoulder about three-fifths of the distance between mid-height and the suture above. From the suture as far as the middle of the obliquely flattened slope, the transverse striae curve backward at an angle of about 80° with the suture. From this point the striae curve more strongly backward, at an angle of 60° with the horizontal, until about 3 mm. below mid-height of the volution, beyond which they curve forward until they assume a radial direction along the lower face of the volution. There is a tend-

ency toward angulation along the lower margin of the umbilicus, and within the umbilicus the inner side of the last volution is striated by relatively coarse transverse lines which curve so as to present their concave sides toward the aperture of the shell. In addition to the conspicuous transverse striae, there are very faint, almost obsolete, revolving ridges, not likely to be noticed except on exceptionally well preserved specimens.

Locality and formation.—Hillsboro, Ohio; from the Guelph formation. From the collection of Henry Pavey, in whose honor this species is named. Similar specimens are found in the Racine of Wisconsin and the Chicago area.

Remarks.—*Straparollus paveyi* is regarded as related to the species described by Lindström³⁹ under the name *Oriostoma discors* Sowerby. In the American species the revolving ridges have become obsolete.

J. A STIGMARIAN ROOT FROM THE CHESTER FORMATION OF ILLINOIS

Dictyophlois Foerste

In the Bulletin of the Torrey Botanical Club, in 1916, a Stigmarian root from the Chester formation at Sample, Kentucky, was described under the new generic name *Dictyophlois*, the species itself being named *Dictyophlois reticulata* Foerste.

Similar Stigmarian roots had long been known in Europe under the name of *Stigmaria stellata* or *Stigmaria ficoides stellata*. As long ago as 1841, Goeppert illustrated this form of root in his *Gattungen der Fossile Pflanzen* (pl. X, fig. 12) from Silesia. It appears to range from Great Britain as far east as Russia.

In Europe, *Stigmaria ficoides stellata* appears to range over about the same territory and at about the same horizon as *Lepidodendron Volkmannianum* Sternberg, which suggests that *Stigmaria ficoides stellata* may belong to the root system of *Lepidodendron Volkmannianum*. Both appear to be especially characteristic of the Culm.

In America, Stigmarian roots of this type are confined to the Chester. *Dictyophlois reticulata*, as already stated, was found

³⁹ Lindström, *Sil. Gast. and Pter. of Gotland*; 1884, pl. 16, figs. 20-36.

in the Chester at Sample, in Breckenridge county, Kentucky. In the State Museum of Natural History at Springfield, Illinois, there is a specimen of *Dictyophlois*, numbered 1718, labelled as coming from the Chester group, at Carroll's place, in Pope county, Illinois. This specimen is described and figured on the following pages. I have been informed by Dr. David White that Stigmarian roots of the *Dictyophlois* type are known also in Appalachian areas, in strata of Chester age.

Whether *Dictyophlois* is to be regarded as founded on differences of generic value can not be determined until its relationship to known aerial stems has been definitely established. In our present state of knowledge it appears to be as distinct as many another genus. Certainly, the reticulated appearance of the area between the attachment areas of the so-called rootlets looks quite different from the corresponding relatively smooth area in *Stigmaria ficoides*.

If a knowledge of the bark and wood structure of the so-called roots or rhizophores of *Dictyophlois* and of *Stigmaria ficoides* were known, it would be possible to determine what is the significance of the reticulated structure on the supposed surface of *Dictyophlois*. No specimens showing such structure are at hand. Therefore, I am forced to base my opinions on such features as are exposed merely by impressions of the surface in its present condition, without any knowledge as to whether these features belong to the original surface of the bark, or to more deep seated structures within this bark.

The American specimens of *Dictyophlois* do not appear to be identical specifically with *Stigmaria ficoides stellata* as figured by Goeppert. The reticulations between the attachment areas of the rootlets appear more complicated, although a change of opinion might be necessary if actual specimens of the European form were at hand.

The figure accompanying the original illustration of *Dictyophlois reticulata* unfortunately was printed in an inverted position, as the location of the shadows might indicate. It was also printed altogether too pale to bring out all of the structure. This is remedied by the illustrations of the Illinois specimen here presented.

Dictyophlois reticulata illinoisensis Var. nov.

Plate XII, and plate XIII, fig. 12.

Cf. *Dictyophlois reticulata* Foerste, Bull. Torrey Bot. Club, 42, 1916, p. 675, pl. 33.

Plate XII presents the appearance of the specimen in its present condition. Figure 12 on plate XIII presents the appearance of an impression of a part of the same specimen, in which the cavities of the first figure stand out as projections.

Specimen 150 mm. in length and about 80 mm. in width; part of a rhizophore, whose original diameter can not be determined. In its present condition the specimen is flattened. The view presented on plate XII is assumed to be that of the exterior of the cortex. The round areas of attachment of the so-called rootlets vary from 3 to 4, occasionally 5 mm. in diameter. They tend to be arranged in diagonally intersecting rows, so as to be from 8 to 13 mm. apart. At these attachment areas the surface of the rhizophore is abruptly depressed, and from the bottom of the pit there rises a short circular elevation with a small central pit. Some of these small central pits have a central tiny elevation. The round areas of attachment are surrounded by a single series of radiating depressions, usually from 20 to 25 in number. These radiating depressions vary usually from 2 to 3 mm. in length, but occasionally are shorter or longer. In the areas between the radiating groups of depressions the meshes of the remainder of the reticulated surface usually average about 2 mm. in diameter, though a few may be as much as 3 mm. in diameter.

Locality and formation.—From the Carroll place, in Pope county, in the southern extremity of Illinois, in the Chester formation.

Remarks.—Evidently the structure of this Illinois specimen is very similar to that of the Kentucky type. The question arises whether they are identical. Apparently the zone of radiating depressions surrounding the attachment areas of the rootlets tends to be depressed below the general level of the surface in the Kentucky type, while in the Illinois specimen the descent

into the pit at the attachment area is more abrupt; but this may be due to inferior preservation of the Kentucky type. In the Kentucky type these attachment areas vary from 13 to 15 mm. in their distances apart as an average, and considering this moderately greater distance apart, the meshes of the reticulated surface between appear relatively coarser. In fact, this difference in the coarseness of the intervening meshes appears sufficient to warrant the use of a distinguishing name for the Illinois specimen, which therefore is called variety *illinoisensis* of the Kentucky type of *Dictyophlois reticulata*.

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PLATE IV

Fig. A. *Leveilleites hartnageli* Foerste. Type, in same slab with *Dictyonema scalariforme creditensis* Foerste. Specimen belonging to Chris Andrew Hartnagel.

Fig. B. *Dictyonema scalariforme creditensis* Foerste. Type, magnified 1.7 diameters. The lower part of the specimen presents the proximal side and the upper part the distal side of the same infundibuliform rhabdosome.

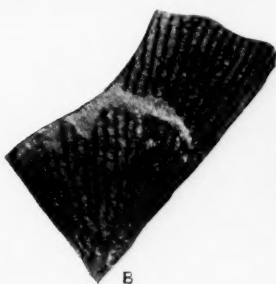
Fig. 25. *Leveilleites hartnageli* Foerste. Both obverse and reverse of the specimen are present. Enlarged views occur on plate IX.

Fig. 26. *Leveilleites hartnageli* Foerste. Reverse of specimen 5. Enlargements of specimens 26 and 5 occur on plates VII and X.

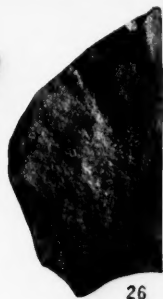
All specimens on this plate are from the base of the Manitoulin dolomite member of the Medinan, in the quarry west of Credit Forks railroad station, in Ontario.



25



B



26

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PLATE V

Figs. 1-12. *Leveilleites hartnageli* Foerste, associated with *Dictyonema scalariforme creditensis* Foerste in specimens 4 and 12. Credit Forks, Ontario; in the Manitoulin dolomite.

The fronds in the upper right hand corner of figure 2 are the reverse of those in figure 15 on plate VI.

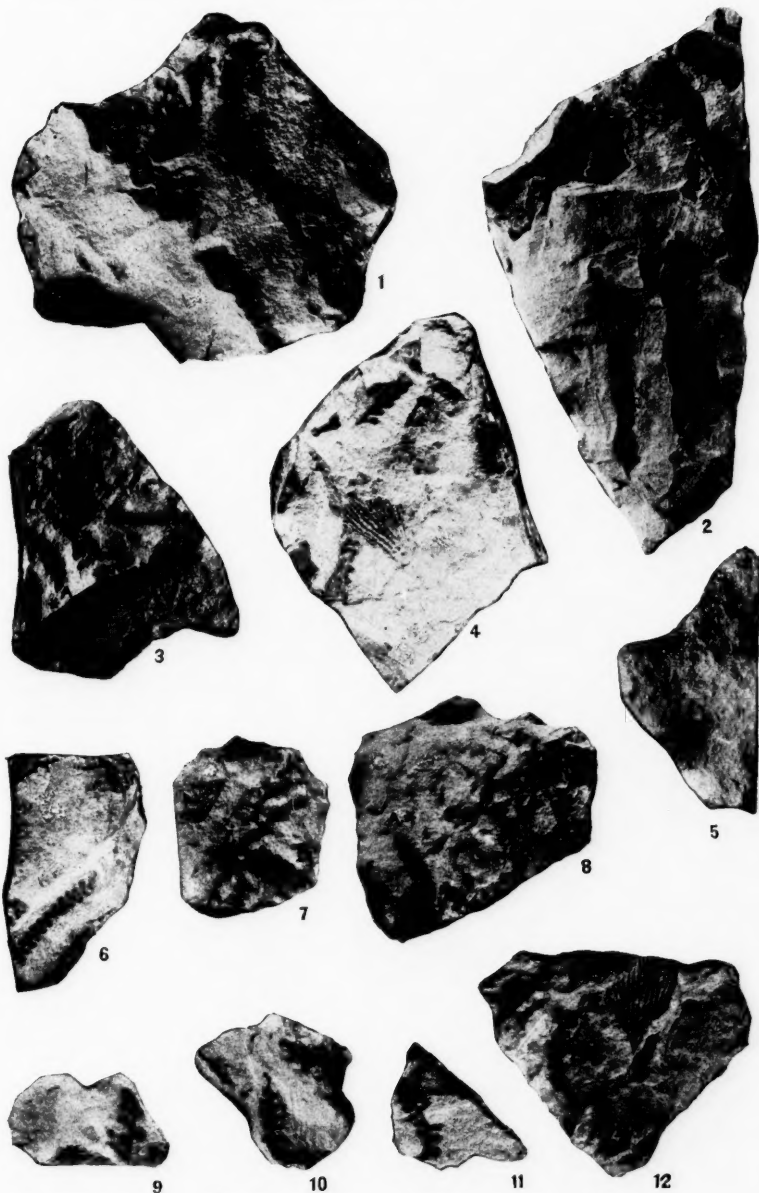
Of specimen 3 both the obverse and reverse are present, and frond A is enlarged on plate VII.

Specimen 5 is the reverse of specimen 26 figured on plate IV, and both are figured enlarged on plates VII and X.

Of specimen 6 both the obverse and reverse are present, and a third fragment contains *Dictyonema scalariforme creditensis*.

Specimen 7 is the reverse of specimen 21, frond B in figure 7 and frond A in figure 21 being the frond enlarged in figure 21 on plate IX. Specimen 8 is the reverse of the opposite side of specimen 21, no part of which is shown in figure 7.

Frond A in figure 8 is enlarged on plate VIII.



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PLATE VI

Figs. 13-24. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario, in the Manitoulin dolomite.

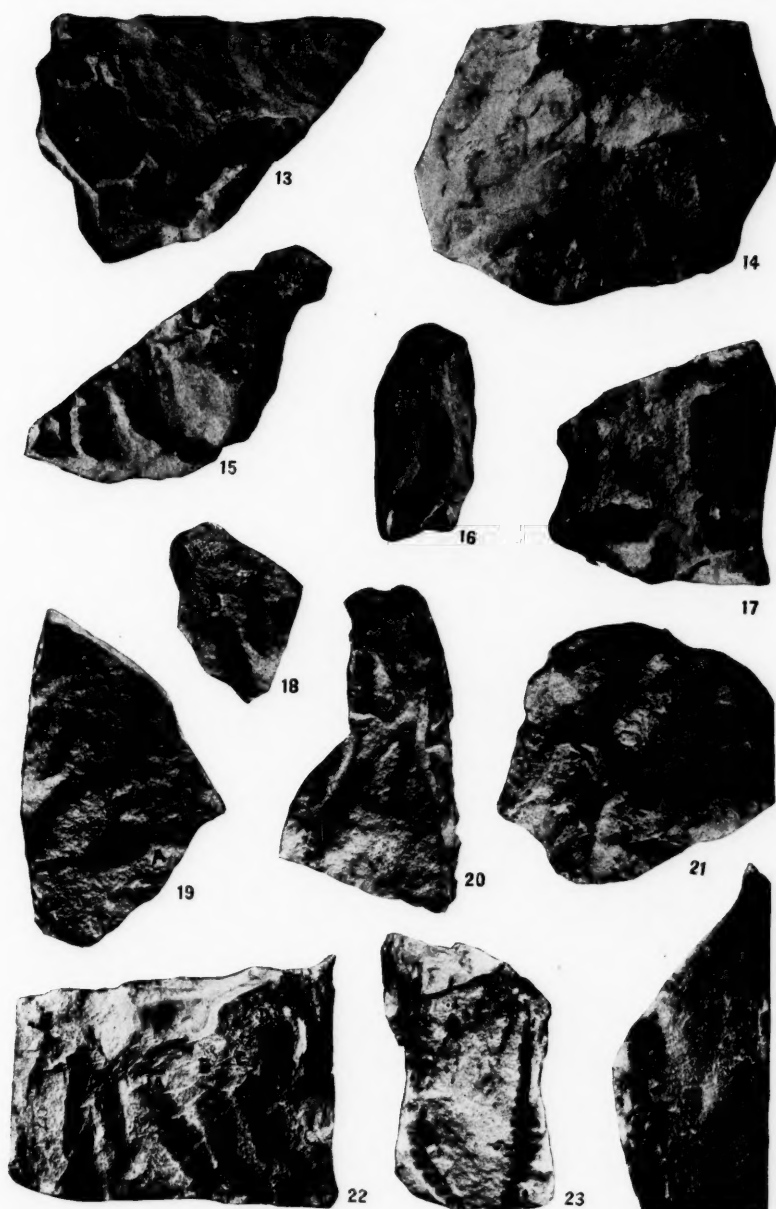
Specimen 13 is the reverse of specimen 17.

Specimen 15 is the reverse of the upper part of specimen 2.

Specimen 16 is the reverse of specimen 22.

Specimen 18 is the reverse of specimen 19, and is enlarged on plate XI.

Specimen 21 is the reverse of specimen 7, and is enlarged on plate IX.



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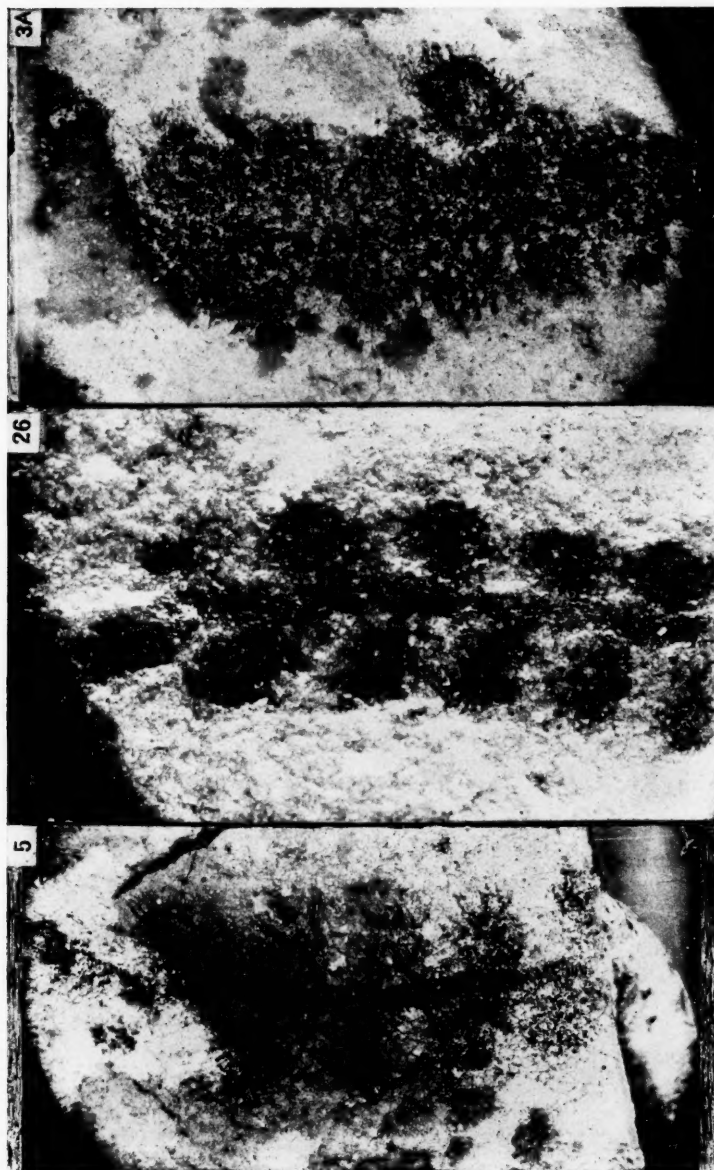
PLATE VII

Fig. 3A. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. View of frond 3A on plate V enlarged 10 diameters. Showing trace of median rachis-like film.

Fig. 5. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. View of frond in figure 5 on plate V, enlarged 10 diameters. Reverse of specimen 26. Reticulated structure of frond shown vaguely in dark part of figure. See also plate X.

Fig. 26. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. View of frond A in figure 26 on plate IV, enlarged 10 diameters. Showing the reticulated structure of the frond.

Photographs by Prof. George H. Hudson, of Plattsburgh, New York; this and the following four plates have been photographed under gum dammar in order to bring out the structural details. Plates X and XI should be examined under a stereoscope.



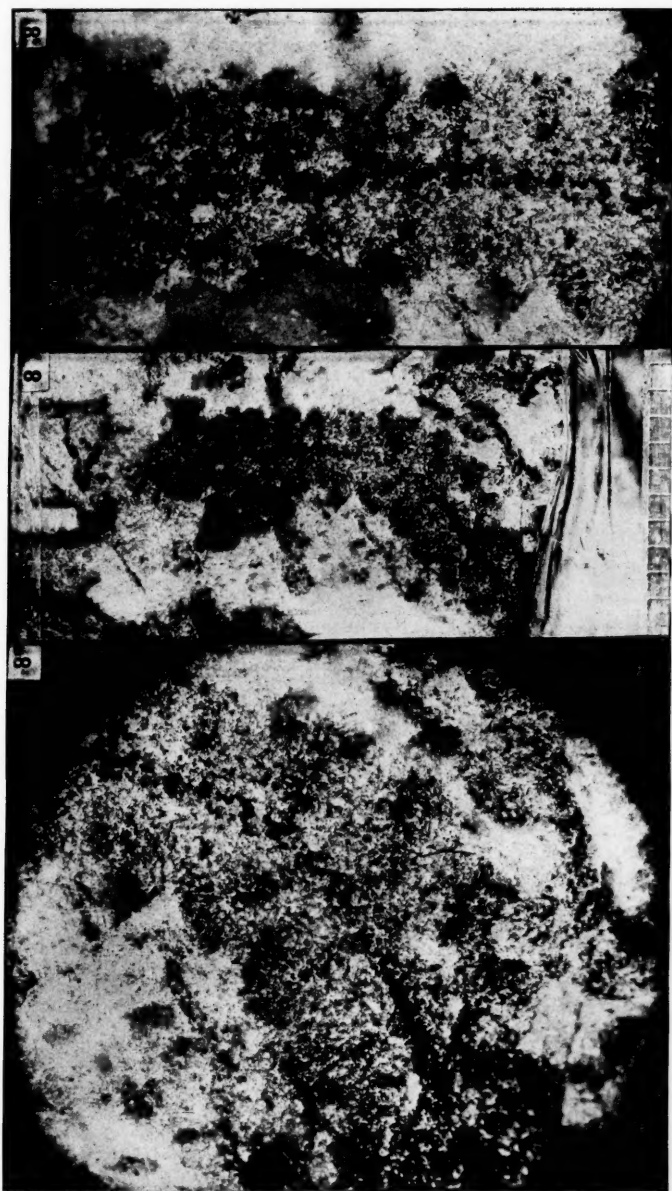
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PLATE VIII

Fig. 8. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. View of frond A in figure 8 on plate V. The middle figure is enlarged 4 diameters. The right hand figure, enlarged 10 diameters, represents the upper half of the same frond, while the left hand figure, also enlarged 10 diameters, represents the lower part of this frond. All figures show the median rachis-like black film. There are traces also of the reticulated structure.

Photographs by Prof. George H. Hudson.



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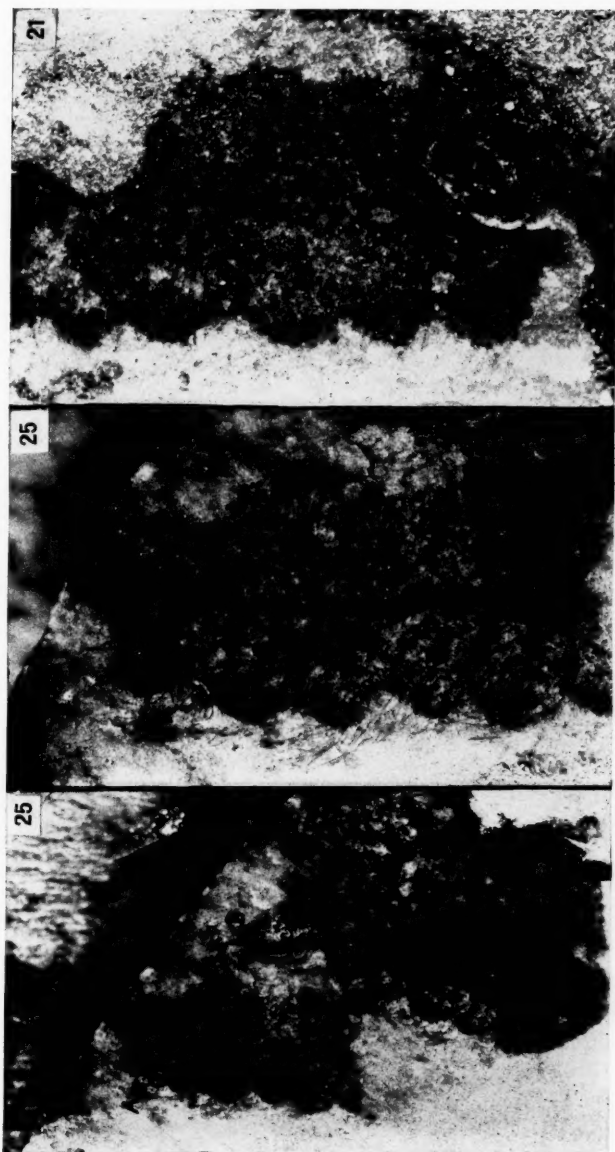
MEDINAN, NIAGARAN, AND CHESTER FOSSILS]]

PLATE IX

Fig. 21. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. View of frond A in figure 21 on plate VI, enlarge 14 diameters. The median rachis-like black film with traces of corresponding lateral films are shown.

Fig. 25. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. The left hand figure is enlarged 4 times, and the middle figure is enlarged 8 times. The middle figure is an enlargement of frond A in the preceding figure, and both figures are enlargements of figure 25 on plate IV. These enlargements show the median rachis-like black films of the fronds and of their lateral lobes, and the reticulated structure of the fibrous mass forming the fronds. Along the left margin of the middle figure on this plate the hair-like fibers attached to the frond are visible in the photograph, but do not show up well in the photoengraving.

Photographs by Prof. George H. Hudson.



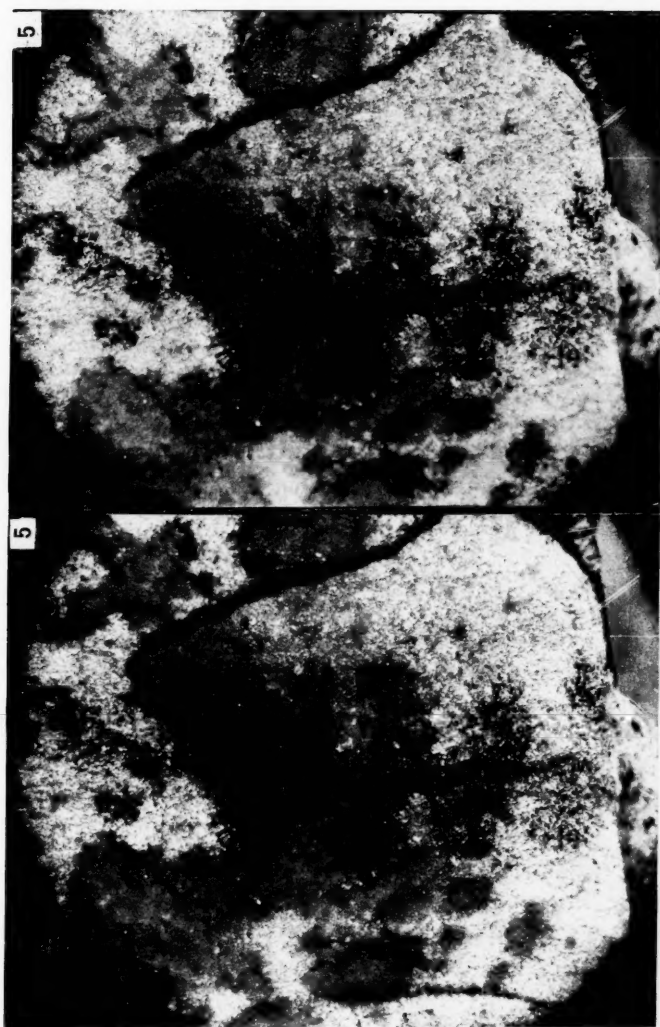
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PLATE X

Fig. 5. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. Both views enlarged 10 diameters, arranged for use with a stereoscope. Same specimen as figure 5 on plate V. This stereoscopic view is valuable chiefly for showing that the fronds consist of something more than a thin flat carbonaceous film. They consist of reticulating fibers occupying a visible depth of space. Some of the black dots to which the hair-like fibers were attached are visible in the photographs, and a few of the hair-like fibers are seen.

Photographs by Prof. George H. Hudson.



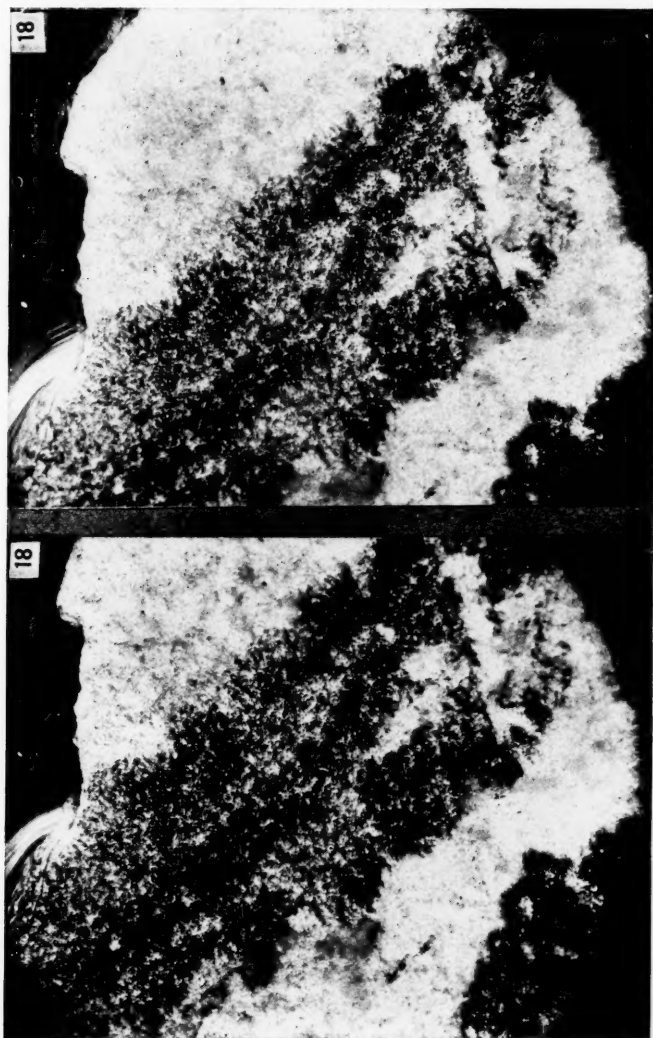
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PLATE XI

Fig. 18. *Leveilleites hartnageli* Foerste. From Credit Forks, Ontario. Both views are enlarged 10 diameters, arranged for use with a stereoscope. Same specimen as figure 18 on plate VI. This stereoscopic view is valuable chiefly for showing that the fronds consist of something more than a thin flat carbonaceous film. Some of the individual fibers can be recognized along the margin of the frond.

Photographs by Prof. George H. Hudson.



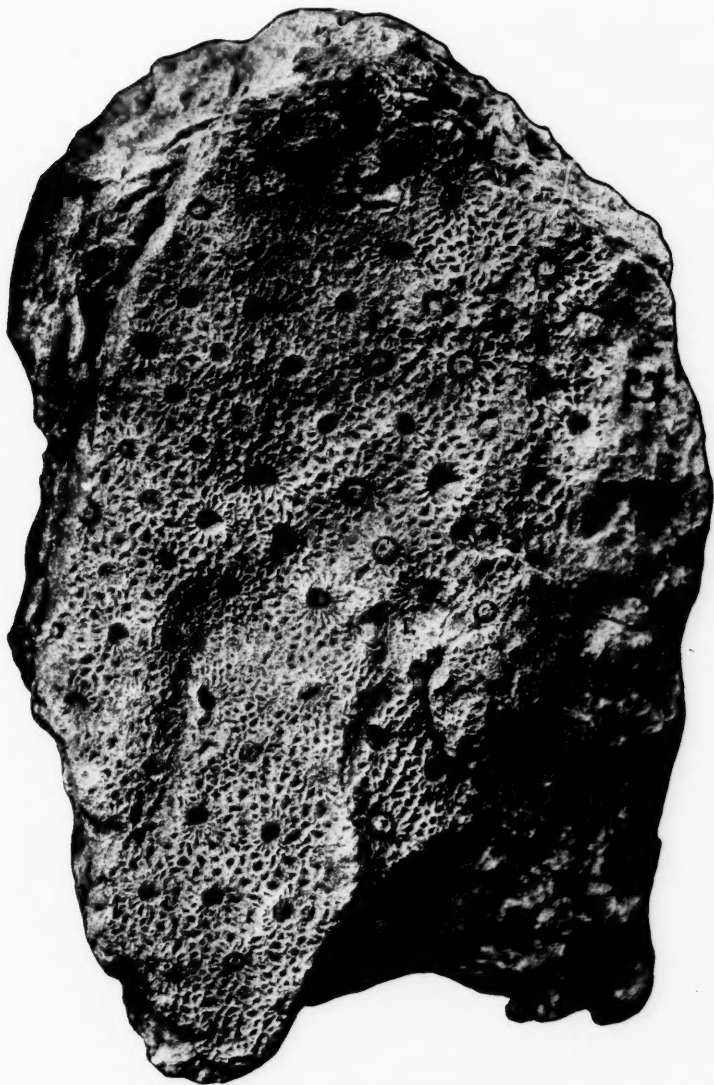
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PLATE XII

Dictyophlois reticulata illinoisensis Foerste. Apparently the outer surface of the bark of one of the rhizophores, showing the circular areas of attachment of the so-called rootlets, and the intervening reticulated area. See Plate XIII for a figure of an impression in clay of part of this specimen. From Carroll place, in Pope county, Illinois.

Specimen No. 1718, State Museum of Natural History, Springfield, Illinois.



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PLATE XIII

Fig. 1. *Modiolopsis orthonota perumbonata* Foerste. Right valve. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 2. *Modiolopsis orthonota* (Conrad). A-E, right valves; F, G, left valves. Credit Forks Ontario; Whirlpool sandstone.

Fig. 3. *Ctenodonta* (?) *creditensis* Foerste. Left valve. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 4. *Ctenodonta* (?) *cataractensis* Foerste. Left valve. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 5. *Ctenodonta* (?) sp. Left valve. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 6. *Schuchertella creditensis* Foerste. Pedicel valve, showing location and length of dental lamellae. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 7. *Dalmanella eugeniensis* Williams. Brachial valve. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 8. *Whitfieldella circularis* Foerste. Brachial valves. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 9. *Lingula* cf. *cuneata* Conrad. Brachial valve. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 10. *Calymene* cf. *cedarvillensis* Foerste. A, cranidium. B, fragment of four segments of thorax. C, pygidium. From residual chert, regarded as belonging in the Laurel member of the Niagaran, loose on top of Jephtha Knob, in Shelby county, Kentucky.

Fig. 11. *Liospira* (?) sp. Credit Forks, Ontario; Whirlpool sandstone.

Fig. 12. *Dictyophlois reticulata illinoisensis* Foerste. Clay cast of part of surface of the specimen illustrated on plate XII.

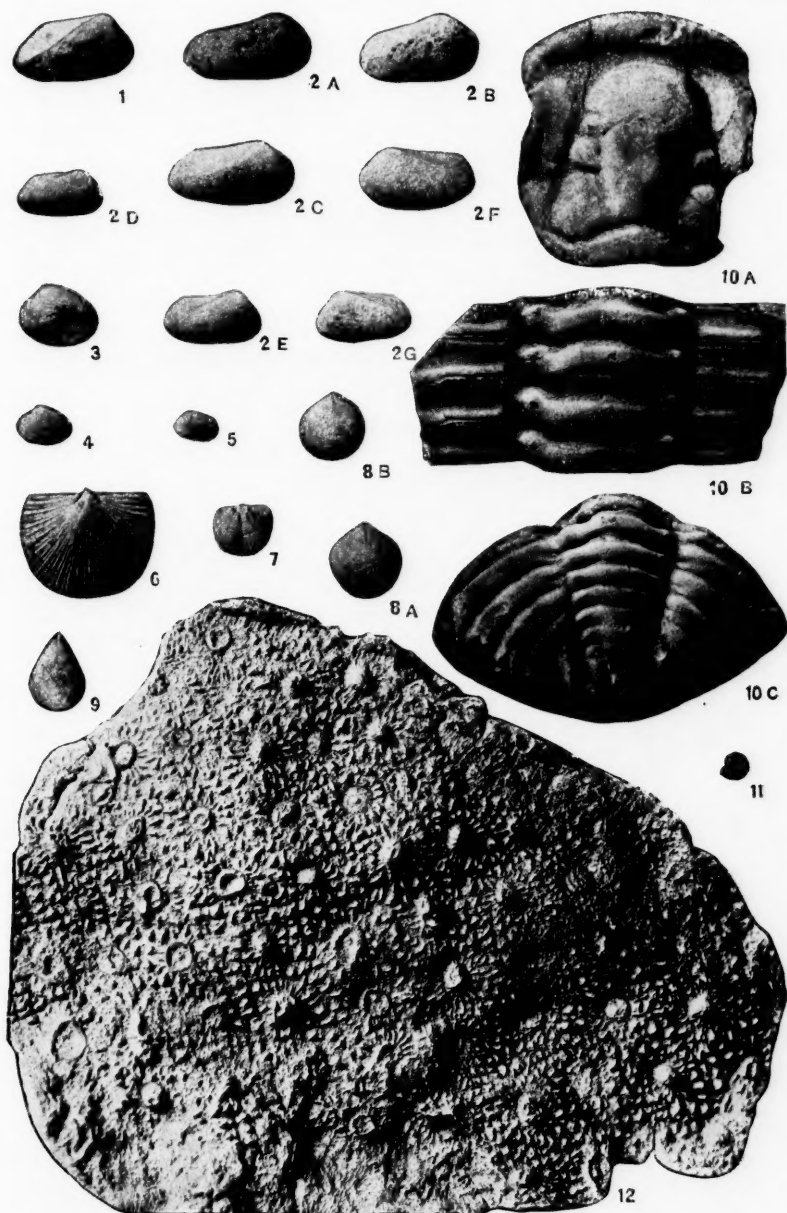


PLATE XIV

Fig. 1. *Calymene altirostris* (Van Ingen) Foerste. A, cranidium. B, C, lateral and upper views of cranidium of chief type. St. Clair Spring, Independence county, Arkansas; St. Clair member of Niagaran. Types. Van Ingen collection. A, magnified 3 diameters; B, C, 2 diameters.

Fig. 2. *Calymene* sp. A, B, C, three pygidia. C, lateral view. St. Clair Spring, Independence county, Arkansas; St. Clair member of Niagaran. Van Ingen collection. Magnified 3 diameters.

Fig. 3. *Proetus vaningeni* Foerste. A, B, C, three cranidia. St. Clair Spring, Independence county, Arkansas; St. Clair member of Niagaran. Van Ingen collection. Magnified 3 diameters.

Fig. 4. *Cyphaspis spinulocervix* (Van Ingen) Foerste. A, B, C, three cranidia. B, C, showing the points of attachment of the nuchal spine. St. Clair Spring, Independence county, Arkansas; St. Clair member of Niagaran. Van Ingen collection. Magnified 3 diameters.

Fig. 5. *Cyphaspis arkansanum* (Van Ingen) Foerste. A, B, C, three pygidia, with a tendency toward a faint marginal depression. St. Clair Spring, Independence county, Arkansas; St. Clair member of Niagaran. Van Ingen collection. Magnified 3 diameters.

Fig. 6. *Straparollus pervetustus* (Conrad). Viewed slightly obliquely, so as to show more of the spire. Lockport, New York; from the Medinan. Original of fig. 3a on plate 4 bis, Pal. New York, 1, 1847. Specimen No. 1434-1, American Museum of Natural History.

Fig. 7. *Modiolopsis orthonota* (Conrad). A, right valve; B, left valve. Originals of figures 1a, 1b, 1c, on plate 4 bis, Pal. New York, 1, 1847. A, from Medina, New York; B, from Lockport, New York; both from the Medinan. Specimen A, No. 1433-1; specimen B, No. 1433-2, in the American Museum of Natural History.

Fig. 8. *Modiolopsis primigenia* (Conrad). Left valve, cast of interior, showing hinge-tooth. Lockport, New York, in the Medinan. Original of fig. 2a on plate 4 bis, Pal. New York, 1, 1847. Specimen No. 1432-2, American Museum of Natural History.

Fig. 9. *Strophonella milleri* Foerste. Pedicel valve. Jephtha Knob, Kentucky, in loose chert from the Laurel formation.

Fig. 10. *Dalmanites* sp. Fragment from right side of pygidium; outline of pygidium unknown. Centerville, Ohio; from basal Silurian, beneath Brassfield limestone.

Fig. 11. *Leptaena centervillensis* Foerste. A, pedicel valve, interior; B, cast of same, to show convexity of valve. Concentric wrinkles are present, as described in the text, but do not show in the photograph, since the direction of illumination chosen was that which brought out the details of the muscular area, rather than the wrinkles. Centerville, Ohio; from the upper part of the Brassfield limestone.

Fig. 12. *Brachyprion* sp. Interior of pedicel valve. Centerville, Ohio; from basal Silurian, beneath the Brassfield limestone.

Fig. 13. *Schuchertella subplana brevior* Foerste. Pedicel valve. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 14. *Whitfieldella* cf. *ovoides* Savage. A, lateral view; B, cast of interior of pedicel valve. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

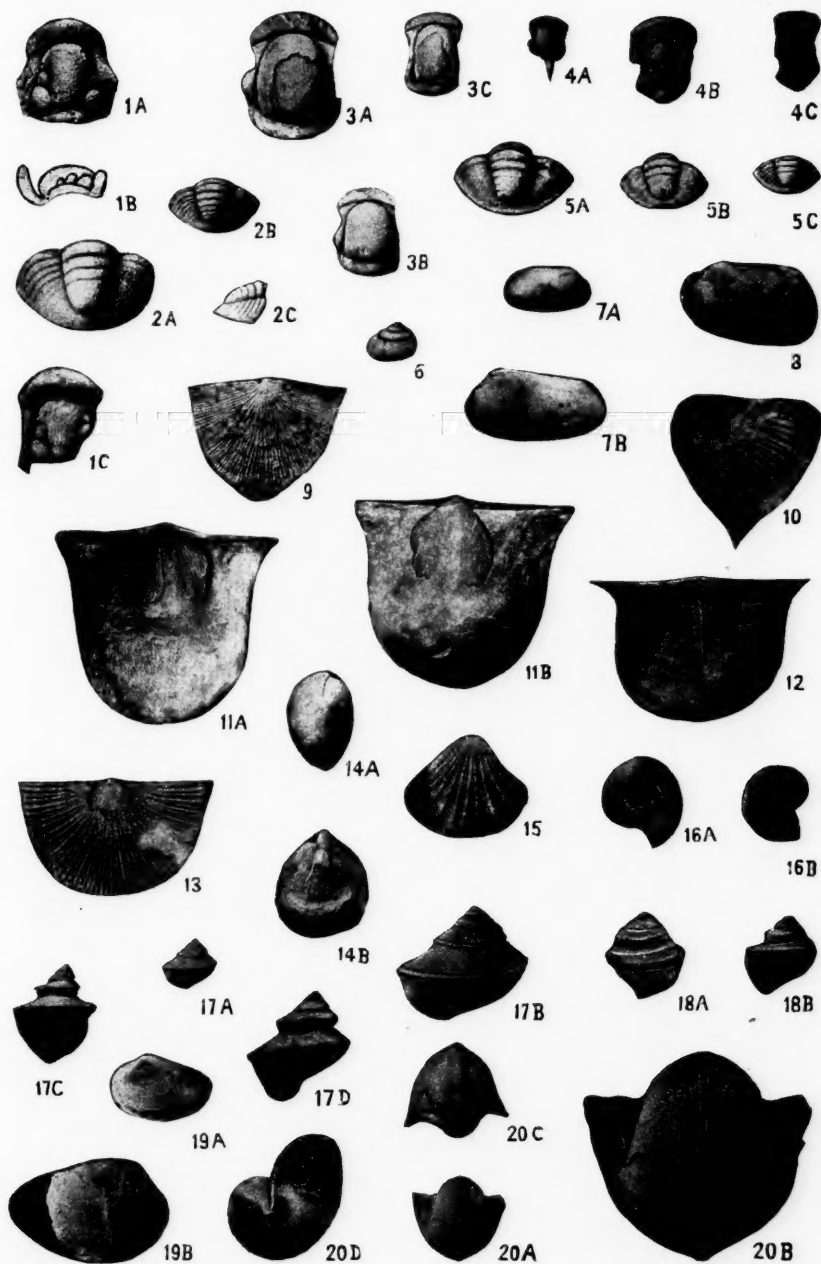


Fig. 15. *Rhynchotretha thebesensis* Foerste. Brachial valve. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 16. *Liospira depressum* Foerste. A, apical view; B, basal view, showing callosity on one side of umbilicus. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 17. *Lophospira ehlersi* Foerste. A, apical part of specimen; B, same specimen enlarged; C, D, entire specimens. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 18. *Lophospira* (*Ruedemannia* ?) *centervillensis* Foerste. A, fragment showing the typical revolving striae along the lower part of the last volution; B, entire specimen, showing general form of shell. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 19. *Ctenodonta* cf. *simulatrix* Ulrich. A., left valve; B, right valve; both magnified 2.4 diameters. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 20. *Bellerophon centervillensis* Foerste. A, aperture facing upward, but margin broken off; B, enlarged view of the same. C, aperture facing downward, but margin broken off. D, attempt at restoration of the margin, in a lateral view.

PLATE XV

Fig. 1. *Straparollus paveyi* Foerste. A, lateral view; B, apical view; C, umbilical view, Hillsboro, Ohio; from the Guelph formation.

Fig. 2. *Spyroceras microtextile* Foerste. A, small fragments; B, the same enlarged; this fragment shows the vertical and transverse striae described in the text, but a greater magnification is needed to show these. C, a longer specimen, apparently belonging to the same species. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 3. *Loxoceras husseyi* Foerste. A, a small fragment showing the vertical surface striae; B, enlargement of the same; C, a typical specimen of larger size, showing the camerae; D, vertical section, showing two of the segments of the siphuncle, and faint traces of two more. Centerville, Ohio; from the basal Silurian beneath the Brassfield limestone.

Fig. 4. *Hormotoma trilineata* var. Foerste. Specimen with a shorter spire than usual. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 5. *Hormotoma trilineata* var. Foerste. Specimen with shorter volutions than usual. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 6. *Hormotoma trilineata* Foerste. A, typical form; B, enlargement of the same; C, another specimen. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 7. *Hormotoma centervillensis* Foerste. A, lateral view; B, enlargement of the same. Centerville, Ohio; from the basal Silurian, beneath the Brassfield limestone.

Fig. 8. *Lyellia thebesensis* Foerste. Jephtha Knob, Kentucky, from loose chert referred to the Laurel formation.

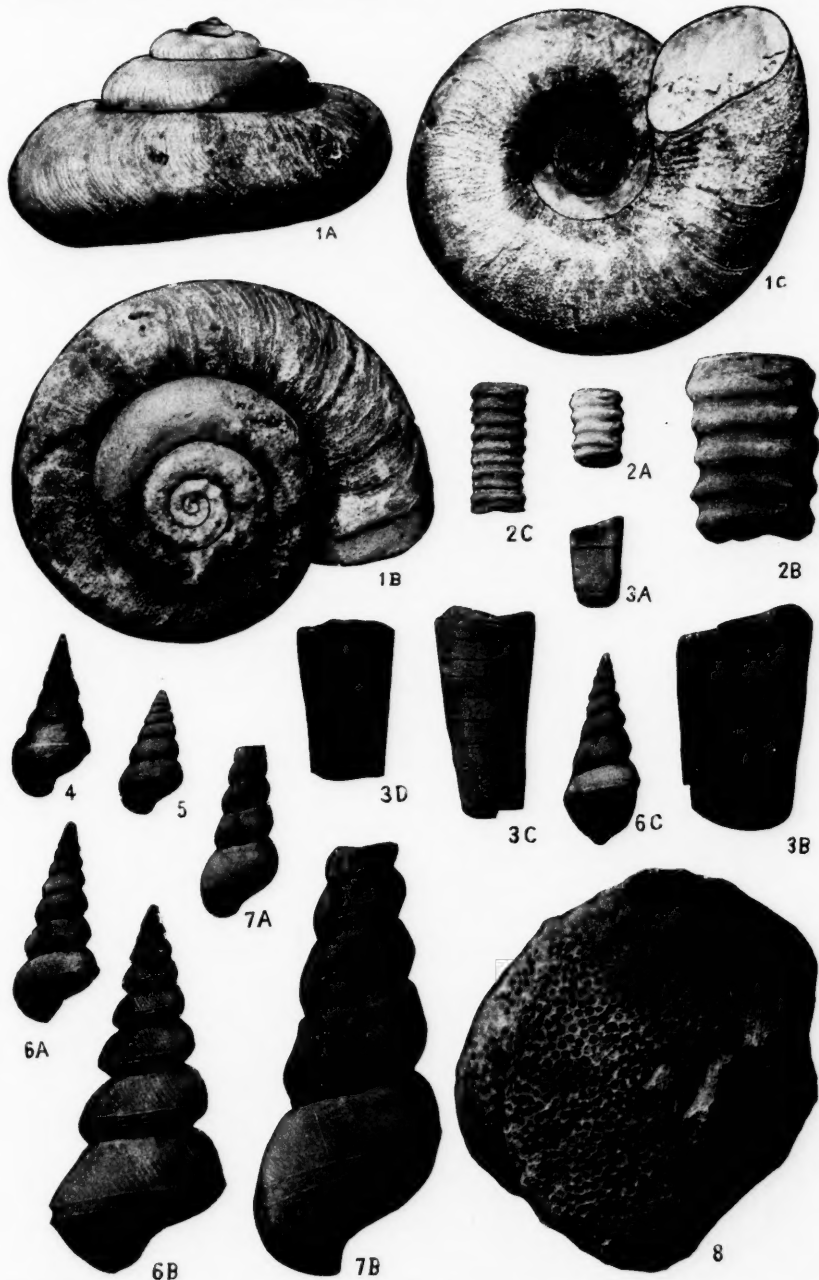


PLATE XV-a

Fig. 1. *Dalmanites* sp. Cranidium with adjacent parts of free cheeks; middle part of anterior outline uncertain. Strongly convex cranidium apparently related to *Dalmanites vigilans* Hall. Cedarville, Ohio; in Cedarville dolomite.

Fig. 2. *Dalmanites* sp. Pygidium associated in same layers with the latter; tip of posterior outline uncertain. Cedarville, Ohio; in Cedarville dolomite.

Fig. 3. *Dalmanites* cf. *Illinoisensis* Weller. Pygidium. Moodie quarry, at Wilmington, Ohio; in the Cedarville dolomite. Collection of Dr. George M. Austin.

Fig. 4. *Cheirurus welleri* Raymond. Hypostoma. Moodie quarry at Wilmington, Ohio; in Cedarville dolomite. Collection of Dr. Charles Welch.

Fig. 5. *Cheirurus welleri* Raymond. Cranidium with posterior part restored. Moodie quarry at Wilmington, Ohio; in Cedarville dolomite. Collection of Dr. Charles Welch.

Fig. 6. *Cypricardinia jepthaensis* Foerste. Right valve. Loose chert, of Laurel age, on Jeptha Knob, Kentucky.

Fig. 7. *Trochonema* sp. Loose chert of Laurel age, on Jeptha Knob, Kentucky.

Fig. 8. *Eccyliomphalus circinatus* (Whiteaves). Apical end of shell with septa. Five-eighths of a mile northeast of Steam Furnace, south of Peebles, Ohio; in strata equivalent to the Guelph formation.

Fig. 9. *Lophospira bucheri* Foerste. Loose chert of Laurel age, on Jeptha Knob, Kentucky.

Fig. 10. *Camarotoechia indianensis* (Hall). A, brachial valve; B, pedicel valve. Loose chert of Laurel age, on Jeptha Knob, Kentucky.

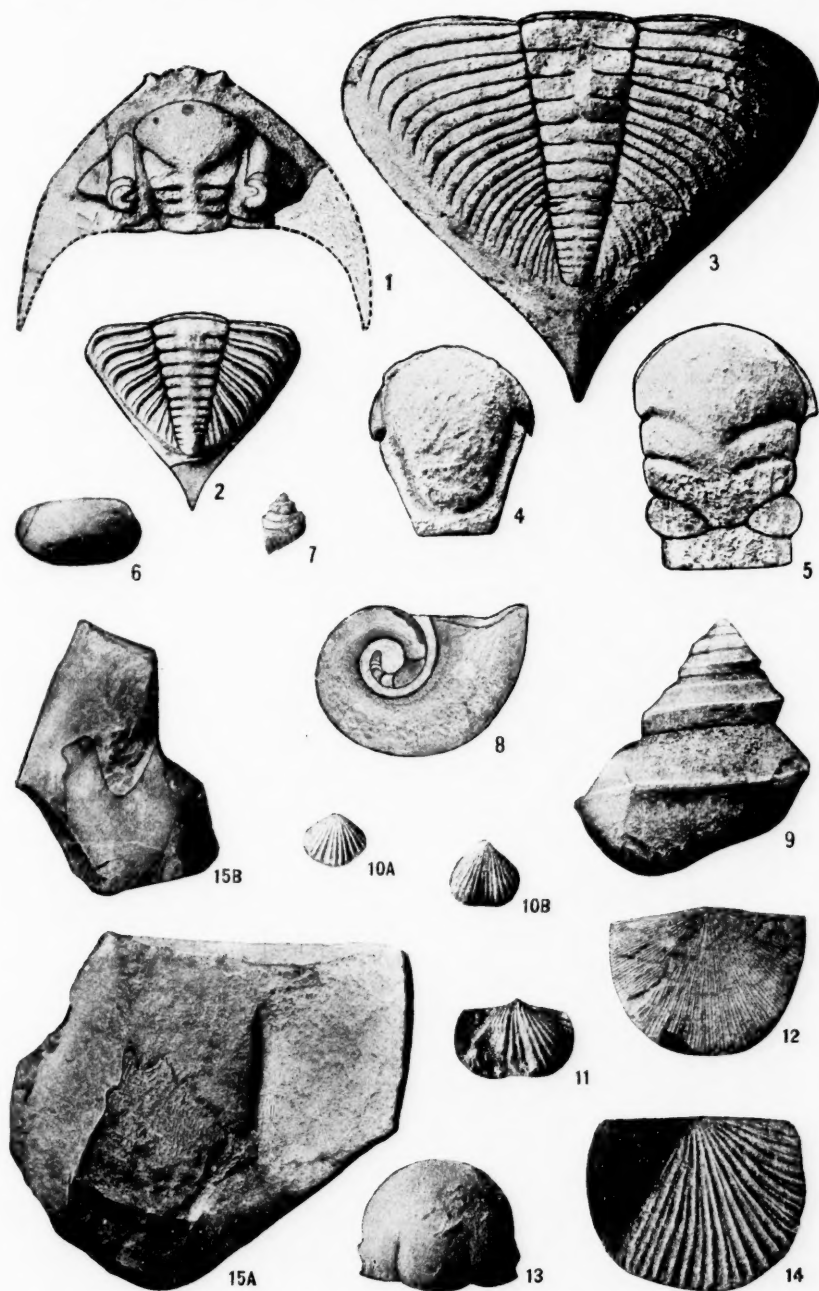
Fig. 11. *Platystrophia daytonensis* (Foerste). Pedicel valve. Loose chert of Laurel age, on Jeptha Knob, Kentucky.

Fig. 12. *Schuchertella* sp. Loose chert of Laurel age, on Jeptha Knob, Kentucky.

Fig. 13. *Iliaenus* cf. *daytonensis* Hall and Whitfield. Loose chert of Laurel age, on Jeptha Knob, Kentucky.

Fig. 14. *Orthis bucheri* Foerste. Brachial valve. From residual Brassfield limestone at south spur of South Hill, on Jeptha Knob, Kentucky. Named in honor of Dr. Walter H. Bucher.

Fig. 15. *Buthotrephis creditensis* Foerste. A, Type specimen, with fragment of frond. B, lobate portion of another frond. Credit Forks, Ontario; in basal part of Manitoulin dolomite.



THE EGG AND LARVA OF HESPERIA JUBA BDV.

A. W. LINDSEY

During the last two weeks of June and early in July, 1922, while the writer was collecting in Modoc County, California, *juba* was on the wing in large numbers. The females were much more numerous than the males, and the prospect of adding a life history of this fine species to our scanty knowledge of the early stages of the Hesperioidea seemed good. Most of the specimens collected, however, were taken on the flowers of a small composite which grew on a dry hillside, and no eggs were obtained until June 29, when a female was observed to place one on a blade of grass at the edge of a small irrigation ditch. This was in a hay field, and the grass was so immature that it could not be identified—a matter which proved immaterial, since the larva ate every species offered to it. Only the one egg was secured. It gave promise of furnishing the complete life history, but the necessity of transporting the larva at the end of the season proved fatal. It ate grasses found at Los Angeles, almost 5000 feet lower in altitude than its native region, and passed its fourth moult in that city, but was then attacked by a mold which caused its death.

Little work of a soundly scientific character has been done on the larvae of the Hesperioidea, hence these notes must be regarded as a pioneer attempt to use the results obtained in the study of other lepidopterous larvae. Prominent among such studies are the recent writings of Mr. Carl Heinrich of the National Museum on the larvae of microlepidoptera. An attempt has been made to follow these papers in the study of the head capsules of the *juba* larva, and Heinrich's use of Dyar's system of nomenclature of the primary body setae has also been adopted in preference to the rather elaborate method of Fracker.¹

¹ Fracker, S. B., Class. Lep. Larvae. 1915.

It is unfortunate that so little material could be preserved for this study, but the complete series of head capsules, the setal map of an abdominal segment of the first instar (fig. 4), sketched in the field, and the maps made from the preserved body in the fifth instar, show some interesting and suggestive things with regard to the possible basis of classification of skipper larvae. It is obvious from the notes recorded that (1) a reduction of primary setae occurs during the first ecdysis, both on head and body, and that (2) it is accompanied by an assumption of a prominent vestiture of secondary setae. The secondary setae of the body have been apparently glandular or sensory in all species observed by the writer. Since the change in vestiture after the first instar agrees with the writer's memory of findings published by Dyar in a paper at present unavailable, it is probably a factor which must be contended with in the entire superfamily, with the possible exception of the Megathymidae and Euschemonidae. The possible persistence of primary setae or tubercles has been pointed out by Fracker,² but without any attempt to interpret specific cases. This attempt is made here, although it must necessarily be supported by other observations before it can be more than a suggestion.

The following paragraphs on the egg and larval stages give the writer's field notes, supplemented by measurements of the head capsules. These are followed by a brief discussion of the chaetotaxy of the larva, based, with the exception of the first instar, upon the preserved fifth stage larva and the head capsules.

Egg: Deposited June 29, about 2:00 p.m., in a damp sunny place close by the edge of a small irrigation ditch, where the humidity must have been much higher than in the localities frequented by the adults. The egg was circular, its flattened base about 1 mm. in diameter. Its height was about 0.75 mm., the sides rounding up to a flattened micropylar area about 0.4 mm. in diameter. Shell white with a yellowish tinge due to the contents. Surface covered with a fine reticulation of raised lines, plainly visible under an eighteen diameter hand lens, though not at all prominent. On July 7 the micropylar area

² Op. cit., p. 127.

showed a small black spot which increased to half the diameter of the egg by the morning of July 9. The larva emerged some time during that day and had eaten all of the free portion of the egg shell when it was observed at 5:00 p.m.

First Instar: Newly hatched larva 2.3 mm. long, 0.5 mm. in greatest diameter. Color yellowish white with black setae. First segment brownish with black cervical shield. First pair of legs black, second pair distinctly suffused with blackish and third pair slightly so. It was difficult to make definite observations of the setae with only a hand lens, but the following may be quoted from notes made in the field:

On the anal plate there is a marginal row of six setae, the next to the outermost long (0.3 mm?) and upturned. All others perhaps not over 0.1 mm. long. Against the pale body they appear dark—it is certain, at least, that they arise from tiny dark tubercles—but against the green of a leaf they appear shining and pale, with enlarged whitish tips.

This suggested glandular hairs, but a lens could not verify the point. The setal map (fig. 4) shows the arrangement of the setae of an abdominal segment. It was checked so carefully, even in bright sunlight, that probably nothing was omitted which could be seen under the low magnification available. Diameter of head capsule 0.6 mm.

Second Instar: The first stage larva began its moult on July 14 and completed it before the morning of July 16. In the second instar all primary setae excepting the two longest on the anal plate were either lost or obscured by the sparse coat of short, dark secondary setae which had appeared. The skin was yellowish and transparent, the general appearance greenish, due to the contents of the alimentary canal. The head, first segment and thoracic legs were extremely dark brown, almost black; the first segment was marked with a transverse anterior line, whitish in color. Diameter of head 0.8 mm.

Third Instar: The second moult began on July 22 and, like the first, was completed before the larva was examined on the morning of the second day thereafter, viz., July 24. In the

third instar the appearance of the larva was much as in the second. Its general color was pale brownish, only slightly tinged with green. The numerous short brown secondary setae were scattered on the anterior third of each segment, and behind this arranged in five or six transverse rows, separated by shallow wrinkles. The setae appeared to have thick pale tips, again suggesting glandular structure. Diameter of head capsule 1.4 mm.

In this stage the larva spun a small cocoon between a blade of grass and the jar in which it was kept, in preparation for its moult, which was begun August 5 and completed before 5:00 p.m., August 6.

Fourth Instar: No differences could be noted aside from the increased size. Diameter of head capsule 2 mm.

On the morning of August 16 the larva had spun another cocoon with large open meshes, in which it completed its fourth moult by the morning of August 18. A few days later the ventral surface of the abdomen showed a patch of white fungus, and when this continued to spread the entire larva was placed in alcohol.

Fifth Instar: Diameter of head 2.6 mm. The head of the preserved larva appeared in all ways similar to that of the fourth instar, as also did the body. Microscopic examination of the preserved specimen, however, disclosed many details which could not be observed with a hand lens in the field. The skin was found to be roughened with numerous stellate prominences, and the abundant secondary setae proved to be glandular or sensory as supposed. These setae varied roughly in accordance with their position on the body. On the back the short form (fig. 5c) predominated. Ventrals they merged into the form shown by figure 5b, while on the sides of the thorax the intermediate form (fig. 5a) was observed. With regard to the presence of primary setae little can be said which is not amply expressed by the maps in figure 3. The presence of secondary setae of ordinary form on the ventral surface made it impossible to be certain that the prominent setae represented were really primary. The ring-like tubercles, which show their hollow centers

only under relatively high magnification, are conspicuous structures. Whether, as suggested by Fracker and as treated here, they represent primary setae or are an entirely different kind of organ, remains to be proved. In any case they are probably of taxonomic value. The first instar map has aided in the interpretation of the fifth instar setae, but is probably incomplete in the ventral region, due to the low power of the lens used in making it.

In the first instar the head was light brown with sparse rounded punctures on the epicranium. The capsules of the remaining stages, in contrast, were so densely blackish brown that they could not be examined by transmitted light, and the punctures covered the entire epicranium and frons, separated by about their own diameter, and merging into roughened sulci toward the clypeus. The change in form of the head is well represented by figures one and two, showing the first and fourth instars. In the fourth instar a few transparent spots appeared in the epicranium and frons, two, rather long, flanking the frontal suture, two pairs in the frons, and two larger patches in front of the ocelli.

The setae of the head in the first instar (fig. 1) included a pair of ultra posteriors and two pairs of adfrontals, all rather prominent, which could not be observed in the later stages. In these, however, they may possibly have been obscured by the numerous short curved secondary setae which were to be found between the punctures. One ocellar seta likewise was found only in the first instar, but none of the setae of the middle group of the labrum could be discovered in this stage, and only one of the mandibular group.

PLATE XVI

LARVA OF *Hesperia juba* Bdv.

Fig. 1 Anterior aspect of head, first instar.

Fig. 2. Anterior aspect of head, fourth instar.

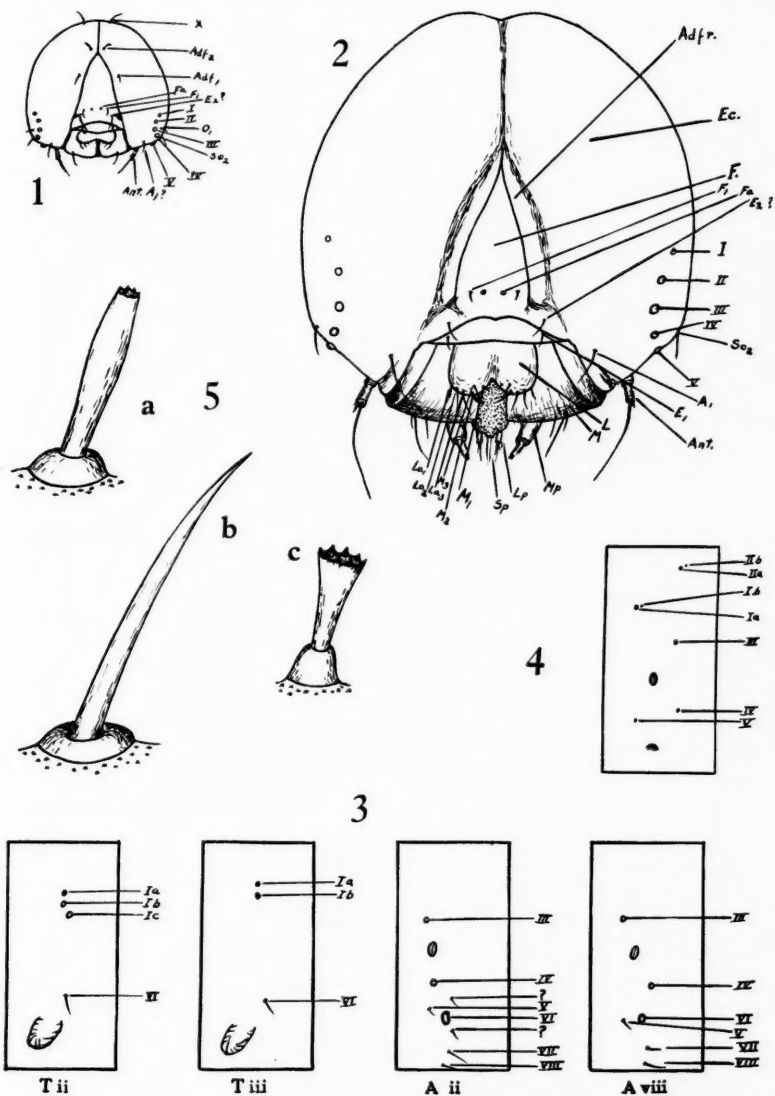
Labels for figures 1 and 2

- F Frons
- Ec Epicranium
- Adfr Adfrontal ridge and suture
- L Labrum
- M Mandible
- Mp Maxillary palpus
- Lp Labial palpus
- Sp Spinneret
- Ant Antenna
- I, II, III, IV, V Ocelli
- X Ultraposterior seta
- Adf₁, Adf₂ Adfrontal setae
- Fa Frontal puncture
- F₁ Frontal seta
- E₁, E₂ Epistomal setae
- O₁ Ocellar seta
- So₂ Subocellar seta
- A₁ Anterior seta
- M₁, M₂, M₃ Median setae of labrum
- La₁, La₂, La₃ Setae of labrum

Fig. 3. Setal maps, fifth instar. T ii and T iii, second and third thoracic segments. A ii and A viii, second and eighth abdominal segments.

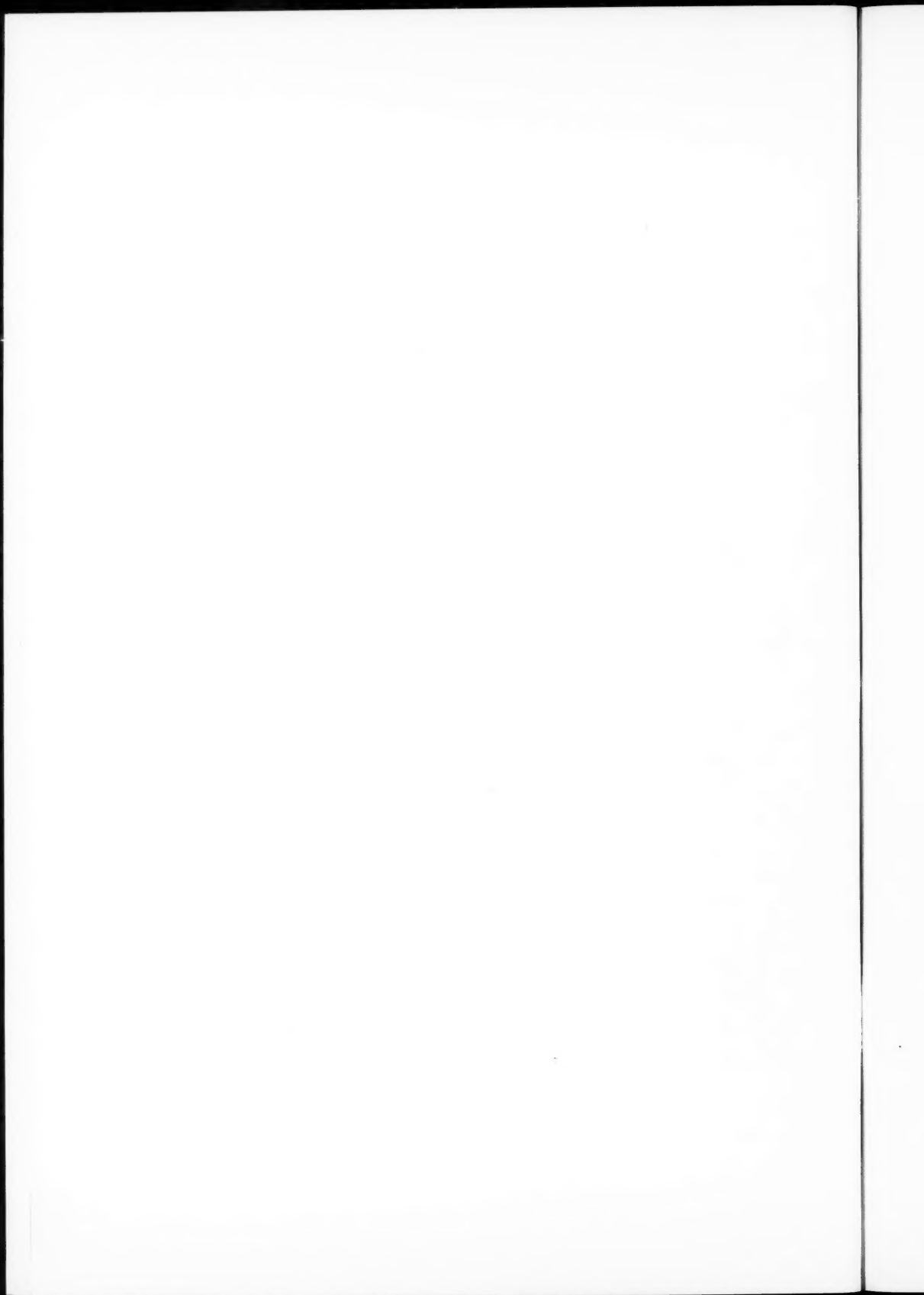
Fig. 4. Setal map of abdominal segment, first instar.

Fig. 5. Secondary setae, fifth instar. a. From ventro-lateral region of thoracic segments. b. From ventral region. c. The most common form, found in lateral and dorsal regions.



A. W. LINDSEY

EGG AND LARVA OF HESPERIA JUBA



THE OCCULTATION OF VENUS BY THE MOON ON JANUARY 13, 1923

P. BIEFELD

An occultation of Venus, like a total eclipse of the Sun, is not in itself of infrequent occurrence, but for any one place on the earth's surface it is extremely rare. The last one visible in this section of the United States happened early in December of 1878.

At Granville (Swasey Observatory) during the night hours preceding the event the sky was almost completely covered. At about 3:00 a.m., however, the sky cleared completely and Venus shone brilliantly some distance east of the Moon.

Venus was about two weeks past maximum brightness but still about 130 times as bright as Aldebaran, the follower of the Pleiades. The Moon was three and one-half days before "new," showing a slender crescent.

It was a superb sight watching the slow but steady approach of the two objects. Apparently a collision seemed inevitable; but only apparently so. The catastrophe was sure to be avoided; the Moon being only about a quarter million of miles from us, while Venus kept at a safe distance of about 47,000,000 miles. The Moon merely covered up Venus in the line of sight by passing over her on the celestial sphere.

Quite a number of last year's and this year's students of Astronomy being present, no attempt was made to observe accurately with the 9-inch the first and second contacts at immersion and emersion, nor were micrometric measures of these points with reference to the north point attempted. It seemed more practicable for the benefit of the students to demonstrate a photographic method for deriving approximately the time of emersion and duration of occultation from two photographic exposures before and after occultation respectively and from the

observation of the time of immersion by the students and myself. No attempt was made to get first and second contacts noting only the time of immersion of the center of the planet.

To have a check on the work Mr. Bannister, a last year's student of Advanced Practical Astronomy, computed the occultation for Granville. A few statements concerning this are perhaps of interest.

THEORY OF OCCULTATIONS

An occultation of a fixed star, approximately an occultation of a planet, may be considered as a special case of an eclipse of the Sun, imagined so far away that its parallax and diameter may be taken equal to zero. Then the cone circumscribing the Sun and Moon in case of a solar eclipse becomes a cylinder in case of a fixed star or planet. The cylindrical shadow cast by the planet shining on the Moon is intercepted by the Earth, or better by a plane passed through the center of the Earth perpendicular to a line passing through the center of the planet and the Moon, and of a linear diameter equal to that of the Moon. The intersection of the fundamental plane with the plane of the Earth's equator plane forms the X-axis of a system of rectangular coördinates of which the Y-axis lying in the same plane points to the north. x and y are then the coördinates of the point where the axis of the shadow pierces the fundamental plane, the center of the Earth being the origin; x and y being expressed in terms of the radius of the Earth as unity.

The "elements" for the prediction of the occultation as found in the American Ephemeris are then as follows:

T , in G. M. T., is the time at which the planet is in geocentric conjunction in Right Ascension.

H is the geocentric hour angle of the Moon and planet at this time.

Y is the y -coördinate of the piercing point of the axis of the shadow cylinder with reference to the fundamental plane at that moment.

x' and y' are the hourly variation in x and y .

From these elements, together with the position of the place of the observer and the declination of the planet, the Mean Time of immersion and emersion of the center of the planet, the angles which these points make with the north point and the duration of the occultation may be computed.

OBSERVATIONS AND MEASUREMENTS

1. A photograph was taken before immersion at time T_1 (point I of fig. 3).
2. Immersion was observed at time T_2 (point E).
3. A photograph was taken after emersion at time T_4 , times T_1 , T_2 , T_4 were recorded on the chronograph in Gr. M. T. (Granville mean time).
4. The two negatives were superimposed and a positive made of same size with the reproducing camera.
5. Prints were made of this positive for measuring with a mm. scale to tenths of millimeters. These measurements were afterwards checked with the comparator of the observatory.

Reductions of observations

T_1 was found to be	17 ^h 35 ^m 14.0 ^s (Gr. M. T.)
T_4 was found to be	18 57 06.0 (Gr. M. T.)
$T_4 - T_1$ was found to be	1 21 52.0 = 34.26 mm.
From this was found	143.38 = 1 mm.
T_2 was found to be (directly observed immersion)	17 ^h 53 ^m 45 ^s .0
$T_2 - T_1$ was found to be (from measurement of print)	18 13.3
T_2 was found to be (from measurement of print)	17 53 27.3
$T_4 - T_3$ was found to be (from measurement of print)	7 52.9
$T_4 - T_1 - [(T_2 - T_1) + (T_4 - T_3)] =$ duration of occultation	55 45.8
$T_4 - (T_4 - T_3) = T_3$ (from measurement of print, emersion)	18 49 13.1

Comparison with calculation

Time of immersion	
Calculated	17 ^h 55 ^m 48 ^s .24 (Gr. M. T.)
Observed: T_2	17 53 45.0
From print: T_2	17 53 27.3
Time of emersion	
Calculated: T_3	18 52 12.12
From print T_3	18 49 13.1

Duration of occultation	
Calculated.....	56 23.88
Measured.....	55 45.80
Point of immersion from north point calculated.....	59°59'57"
Point of emersion from north point calculated.....	330 29 52
Measurements with scale.....	1 mm. = 145. 3
Measurements with comparator.....	1 mm. = 143. 38

PLATE XVII.

- Fig. 1. Photograph taken at time T_1 .
 Fig. 2. Photograph taken at time T_2 .
 Fig. 3. Diagram of two photographs superimposed.

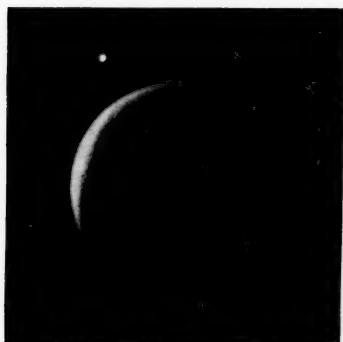


Fig. 1

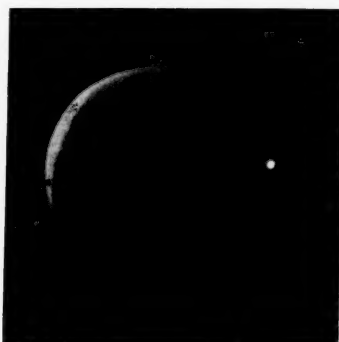


Fig. 2

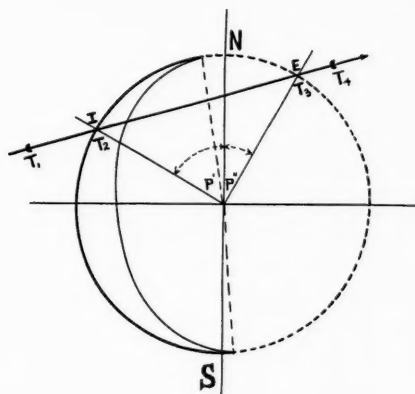
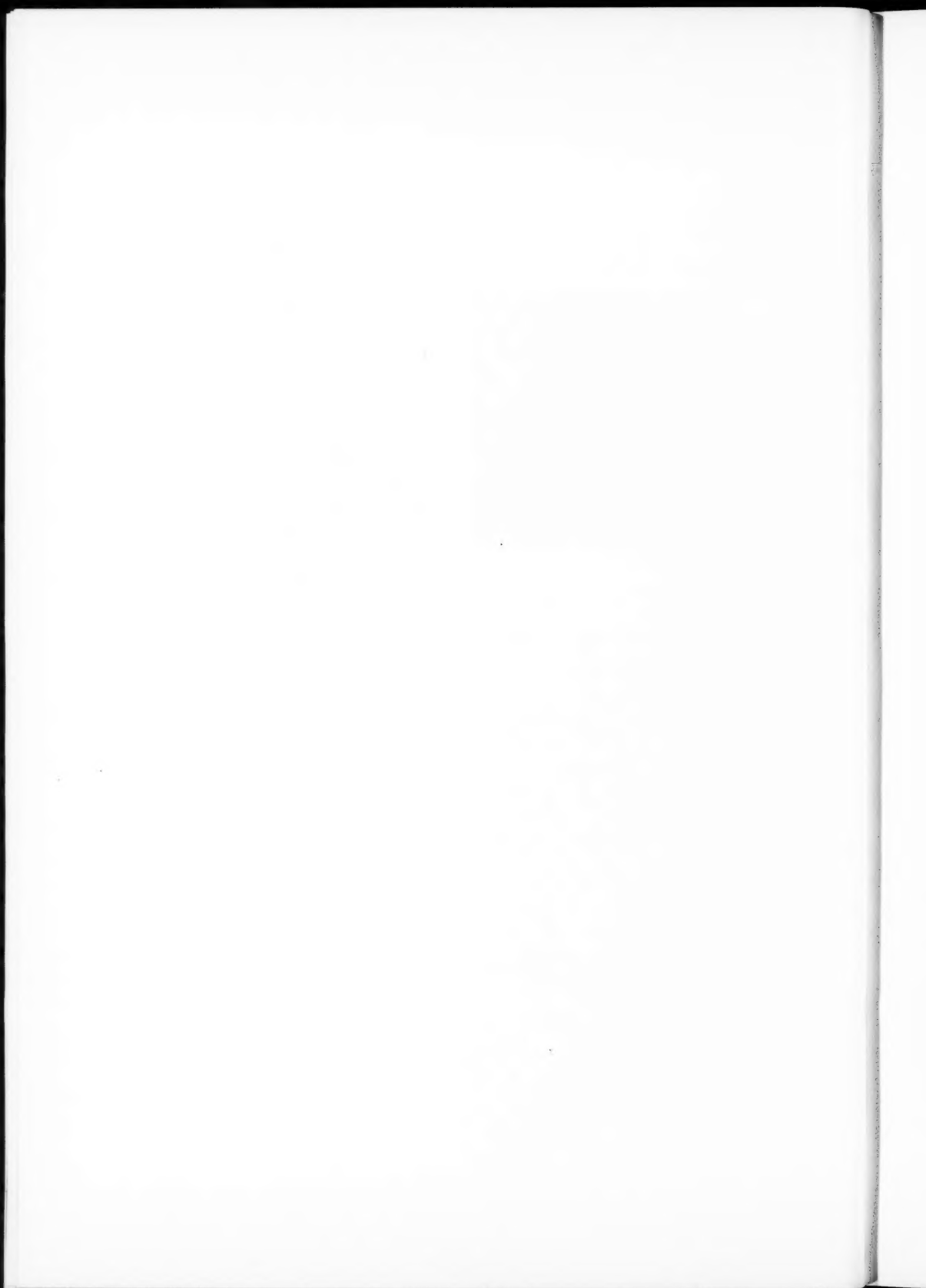


Fig. 3

P. BIEFELD

OCCULTATION OF VENUS BY MOON



A BOTANICAL SURVEY OF THE CAMPUS OF DENISON UNIVERSITY¹

DWIGHT MUNSON MOORE

INTRODUCTION

General location. The campus of Denison University is one of the most attractive spots in the state of Ohio. The greater part of it is on a hill at the northern margin of the village of Granville, situated near the center of Licking County, close to the geographic center of the state. Recent additions to the campus have increased its area to approximately 350 acres. Of this, Shepardson College occupies about one acre, Granville College about fifty acres, and the remainder composes Deeds Field, a great recreation and athletic field, and the College Farm.

Scope of this paper. The present study is limited to the phanerogams of that part of the campus bounded by Burg street on the west, College street on the south, Mulberry street and its northward extension on the east, and the northern edge of the College woods, hereafter called the North Woods, on the north. It is hoped that the paper may later be supplemented with a study of the rest of the campus.

Geology and physiography. The region is near the western edge of the Allegheny Plateau, within the zone of transition between the maturely dissected upland occupying the greater part of southeastern Ohio and the undulating lowland of central western Ohio. One of many hills of a rolling upland, intersected by streams, has been chosen for the campus. Its summit rises slightly above 1100 feet in altitude, and overlooks the broad flat-floored valley of Raccoon Creek which flows eastward along the southern foot of the hill at an elevation of about 900 feet

¹Contribution from the Botanical Laboratory of Denison University, No. XIII.

above the sea. The north slope of College Hill is much shorter and more abrupt than the principal south slope.

The rocks underlying the region are indicated in the accompanying diagram (fig. 1). All belong to the Waverly Series, of Mississippian age, and are grouped by geologists into two formations, the Logan and Cuyahoga, each comprising several members. The top of College Hill is composed of a rather coarse sandy shale or sandstone, the Allensville member of the Logan formation. Beneath this, and outcropping near the west margin of the campus at the "Biological Pool" is the Byer sand-

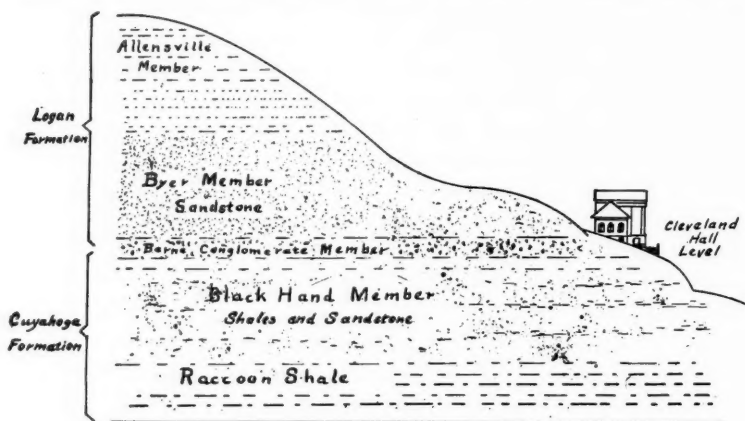


FIG. 1. DIAGRAM SHOWING GEOLOGIC STRUCTURE OF COLLEGE HILL

stone, a freestone which has been quarried at several places on the higher slopes of the hill. The Berne conglomerate beneath the Byer marks the division between the two formations, named above. It is a rather inconspicuous bed, 6 to 18 inches thick, composed of clean quartz pebbles in a sandy matrix. The Black Hand and Raccoon members of the Cuyahoga are sandstones interspersed with sandy shales of quite variable thickness and composition.

All of these on weathering produce a rather loose and more or less sandy soil which is found on the greater part of the campus. Where shales predominate, however, there is a stiffer clay

soil which in places packs hard and is unfavorable for the growth of many plants. The entire region has been covered at least twice by ice sheets which left a thin and scattered deposit of glacial drift. In consequence the surface is quite gravelly at many places.

Climatology. The data for this topic have been taken more or less completely from a report compiled by J. Warren Smith, covering the climate and weather in south central Ohio, in the general summary of climatological data for the United States. No records have been made in this area by the writer, but the data for Columbus, 28 miles distant, extend from 1878 and these have been used.

The monthly mean temperatures in degrees Fahrenheit and the average monthly rainfall in inches at Columbus are as follows:

	MONTHLY MEAN TEMPERATURES (31 YEARS OF RECORDS)	AVERAGE MONTHLY RAINFALL (30 YEARS OF RECORDS)
January.....	28.9	2.97
February.....	30.1	3.01
March.....	39.6	3.49
April.....	51.1	2.84
May.....	62.5	3.80
June.....	71.0	3.41
July.....	75.2	3.65
August.....	72.7	3.21
September.....	66.9	2.41
October.....	54.7	2.32
November.....	41.8	2.91
December.....	32.7	2.66
Annual.....	52.2	36.68
Growing season.....	66.6	

The absolute extremes of temperature for the central part of Ohio are 108° and -34°. These are important because of their possible effect in limiting the growth of vegetation, tending to control the northern limits of many species.

The average date of the last killing frost in spring is April 30, of the first killing frost in the autumn, Oct. 2. The average growing season is therefore about 155 days in length. However, the minimum growing season is about 110 days. "Precipitation is quite uniform over the whole section (in which our area is located) and averages about 38 inches per year." "In general there is the greatest average rainfall in June and July and the least in October."



FIG. 2. THE NORTH WOOD IN EARLY SPRING, SHOWING NATURE OF UNDERGROWTH

ECOLOGY

The natural growth of vegetation has been changed for ornamental purposes, except that of the north hillside, which is almost a virgin forest. The area thus may be divided into wooded areas and open tracts. Among the first there are two: the North or College Wood (I) and the West Wood (II). Of the open tracts four may be distinguished, viz.: the West campus (III), South hillside (IV), East campus (V) including south-east hillside, and the central campus (VI).

The wooded areas

I. The College Wood is a typical mesophytic wood, principally of beech, maple, elm, ash, and only a few oak trees. This might be termed a moist wood. The forest floor presents an excellent example of seasonal plant succession. In April the floor is almost entirely covered with the two *Dicentras*, and *Dentaria lacinata*, with a generous sprinkling of *Viola cucullata*



FIG. 3. THE FLOOR OF COLLEGE WOOD IN SPRING, SHOWING HYDROPHYLLUM, GALIUM AND THE DICENTRAS

and *pubescens*. All of these are quite low forms which must complete their short period of photosynthetic work before other larger plants overshadow them.

In May there is a greater profusion of *Hydrophyllum* and *Chelidonium* with *Galium aparine* pushing upward. Late in May and early June these have mostly given way to *Impatiens biflora* and various other scattered taller forms.

Later in the summer these forms have given place to various Asters, especially *Aster cordifolius*, and to *Eupatorium urticaefolium*.

This wood presents a good illustration of forest succession. The majority of the trees are beech and maple, while the oaks and chestnut appear to be among the oldest. But among the young trees coming on there are almost no oaks, chestnut, or hickory while there is an abundance of maples, beech, elms, and wild cherry. This clearly shows that the oaks, hickories and chest-



FIG. 4. THE NORTH WOOD, WITH A DENSE GROWTH OF HYDROPHYLLUM

nuts are losing ground and will all disappear within the coming generation, giving place entirely to the others which are dominant among the seedlings.

Recently an effort has been made to save some of the older beeches which have become hollow, by the application of tree surgery. This seems to have been successful in several cases.

Another recent introduction in this wood is the building of a Greek temple which serves as the background for the stage of an outdoor theater in the center of the wood. Naturally the use of the wood for this purpose will have a serious effect upon

the plant forms which happen to be in their period of flower at the time the amphitheater is used. But this may not be great if its use is not carried too far.

II. In the West Wood, the trees are much the same, with the beech most abundant then the sugar maple, elms, black walnut, and wild cherry making up the most of the remainder. Here is noticed, even more than in the North Wood, that it is the beech and maple that make up the majority of the young

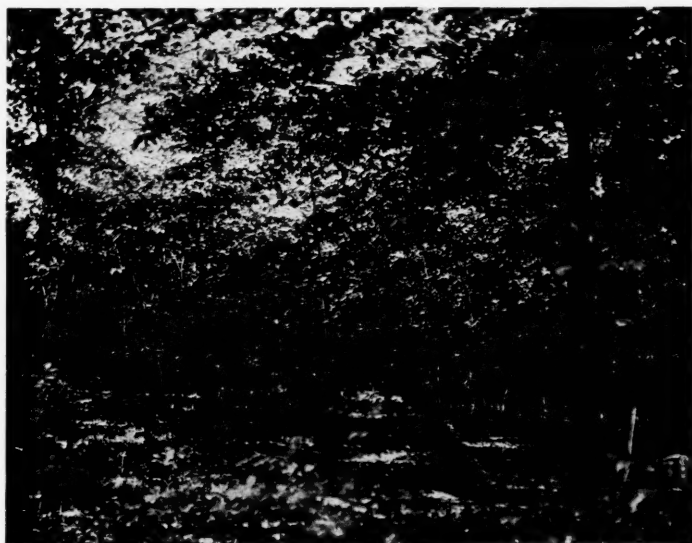


FIG. 5. THE WEST WOOD

trees. Thus this wood will continue to be a beech-maple association through the next generation.

The soil here is much drier, due probably to the southern exposure, a more open wood, and the fact that the soil is thinner over the underlying strata of rock.

Owing to the moisture conditions, the ground flora is more limited than in the North Wood. Here are found principally *Sanguinaria canadensis*, *Podophyllum peltatum*, *Clatonia virginica*; various species of *Geum*, *Galium*, *Desmodium*, and *Carex*;

also *Bidens bipinnata*, *Rubus allegheniensis*, and *Solidago caesia*. It is quite interesting to note the entire absence here of the *Hydrophyllum* and the *Dicentras* which are so profuse in the North Wood.

III. Of the open tracts the west section is perhaps the driest. There are several trees scattered over the larger part of it, and west of the library these are numerous enough to make it quite shaded. The prominent trees are *Fagus grandifolia*, *Fraxinus americana*, *Ulmus americana* and *fulva*, and *Acer saccharum*. Of the herbaceous plants the most prominent are:

<i>Andropogon virginicus</i>	<i>Dactylis glomerata</i>
<i>Danthonia spicata</i>	<i>Erigeron annuus</i>
<i>Poa compressa</i>	<i>Erigeron philadelphicus</i>
<i>Poa pratensis</i>	<i>Capsella Bursa-pastoris</i>
<i>Juncus tenuis</i>	

IV. The south hillside has the flora of an open meadow and includes several grasses and others:

<i>Achillea millefolium</i>	<i>Lactuca scariola</i>
<i>Ambrosia artemisiifolia</i>	<i>Poa pratensis</i>
<i>Asclepias syriaca</i>	<i>Ranunculus abortivus</i>
<i>Daucus carota</i>	<i>Rumex acetosella</i>
<i>Dactylis glomerata</i>	<i>Rumex crispus</i>
<i>Erigeron annuus</i>	<i>Rumex obtusifolius</i>
<i>Erigeron philadelphicus</i>	<i>Saponaria officinalis</i>
<i>Galium aparine</i>	<i>Solidago rugosa</i>
<i>Galium concinnum</i>	<i>Solidago serotina</i>
<i>Hypericum mutilum</i>	

However at the foot of the hill, a line of Spruce trees casts such a shade that there are but a few forms, especially *Galium aparine*, *Geum vernum*, *Menispermum canadense*, *Psedera quinquefolia*, *Ranunculus abortivus*.

But taken as a whole the south hillside has the widest variety of any group studied. This appears to be due to the abundant sunlight and rather moist soil, brought about by a "springy" condition of the underlying rock strata. Also the fact that this receives very little attention during the year—it being mowed not more than twice in the twelve-month—permits the introduction, growth and fruiting of many new and varied forms.

Among the trees that may be mentioned are only such as have been planted for ornamental purposes. There are found here the following: Scotch Pine, Norway Spruces, Kentucky Coffee Tree, Norway and Silver Maples, Japan Maple, Osage Orange.

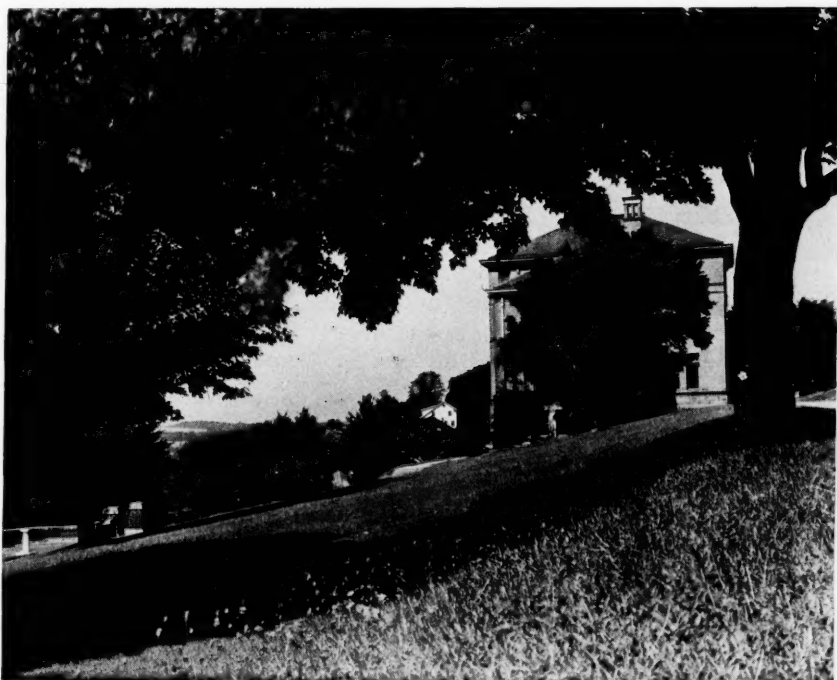


FIG. 6. THE SLOPE OF THE CENTRAL CAMPUS FROM THE HILLTOP TOWARD THE SOUTH PLAZA

V. The east hillside and campus are quite similar to the south hillside in most respects. The slope is probably more abrupt at first, becoming more nearly level lower down.

The trees that have been planted on this slope are:

Alnus glutinosa
Betula Alba
Chionanthus virginica
Corylus avelana

Betula populifolia
Cercis canadensis
Morus rubra
Platanus occidentalis

VI. The central campus has the constant attention of a caretaker, and for the greater part is carefully mowed as often as once a week. This practice has reduced the number of forms to only those which are naturally low or can adjust themselves to these conditions. Here we find principally:

<i>Agrostis alba</i>	<i>Stellaria media</i>
<i>Cerastium vulgatum</i>	<i>Taraxacum officinale</i>
<i>Plantago lanceolatus</i>	<i>Veronica arvensis</i>
<i>Plantago major</i>	<i>Veronica serpyllifolia</i>
<i>Poa pratensis</i>	
<i>Prunella vulgaris</i>	

In this area also have been planted such shrubs and trees as

<i>Acer rubrum</i>	<i>Crataegus Crus-galli</i>
<i>Acer saccharum</i>	<i>Ulmus americana</i>
<i>Aralia spinosa</i>	<i>Ulmus fulva</i>

Artificial grouping has been carried out around all the buildings and at the principal entrances. The accompanying views of the east entrance show the masses of *Kerria*, *Rosa*, *Rhodotypos*, *Forsythia* and *Symphoricarpos*.

Around the buildings are found a number of species of *Deutzia*, and *Spirea*, as well as *Berberis*, *Forsythia*, *Kerria*, *Lonicera*, *Philadelphus*, *Symphoricarpos*. These introduced species are bunched and so selected that there are some of them in flower from the opening of the *Forsythia* in April through the roses in the summer and leaving the attractive white berries of *Symphoricarpos* in the fall.

FLORA

In making the study of the flora of the campus, the writer found it necessary to start from the beginning as there was absolutely no record of any plants of this particular region.

No effort has been made to make a complete collection of the various forms found, but when any were found which the herbarium of the University did not contain, they were added to it.

Verification of the identification of the plants given below in the list has been made by reference to and comparison with the herbarium of the department of Botany of Denison University.

The nomenclature used is that of Gray's *New Manual of Botany*, 7th Edition, except in the case of the exotics which are

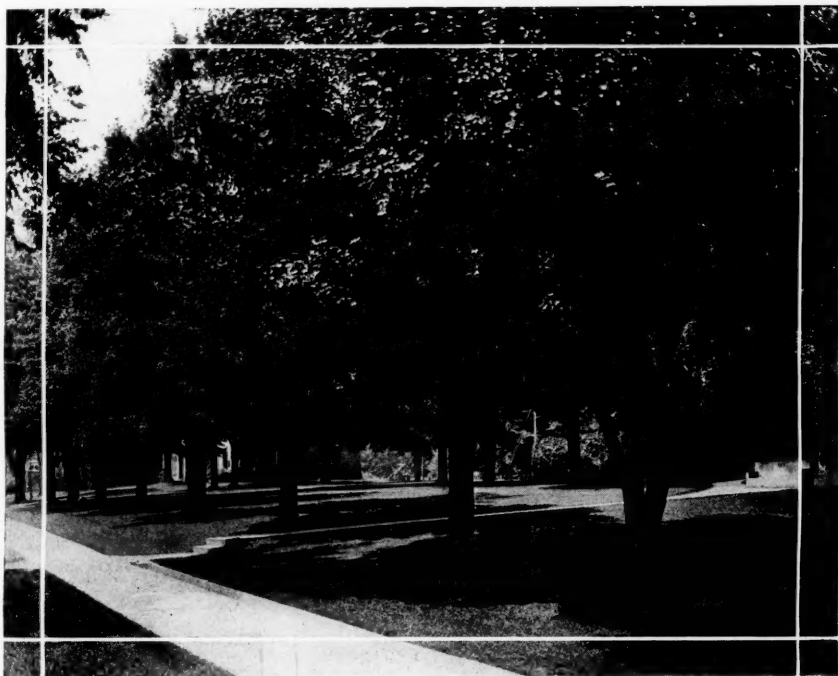


FIG. 7. THE CAMPUS ON THE HILL

not included in the *Manual*. In these cases Gray's *Field, Forest and Garden Botany* and Bailey's *Cyclopedia of American Horticulture* have been used. Britton and Brown's *Illustrated Flora of the Northern States and Canada* has been freely used in the identification of the plants.

The Flora as follows is listed in the order given in the *Check list of the plants found in Gray's Manual*, published by the Gray

Herbarium of Harvard University. Such plants as are quite evidently not growing in their natural habitat or have been set out on the campus are printed in italics.

GYMNOSPERMAE

Ginkgoaceae—Ginko Family.

Ginkgo biloba L. Maiden-hair tree. Back of Marsh Hall.

Pinaceae—Pine Family.

Abies concolor Lindl. White fir. IV.

Juniperus Virginiana L. Red cedar. IV, and a few scattered seedlings.

Picea abies (L.) Karst. Norway spruce. II, IV, V.

Pinus strobus L. White pine. One small tree behind Cleveland Hall.

Pinus sylvestris L. Scotch Pine. I, IV.

Taxodium distichum (L.) Richard. Bald cypress. Behind Marsh Hall.

Thuja occidentalis L. Arbor vitae, White cedar. Near Cleveland Hall and near entrances.

ANGIOSPERMAE

Graminae—Grass Family.

Agropyron repens (L.) Beauv. Couch grass. III.

Agrostis alba L. Red top. General in III, IV, V, VI.

Andropogon virginicus L. Virginia beardgrass. III, V.

Bromus ciliatus L. Fringed brome-grass. I.

Dactylis glomerata L. Orchard grass. III, IV, V.

Danthonia spicata (L.) Beauv. Wild oat-grass. III, IV, V.

Digitaria sanguinalis (L.) Scop. Crab grass. IV.

Eragrostis megastachya (Koeler) Link. Stink-grass. V.

Eragrostis pilosa (L.) Beauv. (Jones.)

Festuca nutans Speng. Nodding fescue grass. I.

Koeleria cristata (L.) Pers. Koleria. VI.

Lolium perenne L. Darnel. IV.

Muhlenbergia Schreberi J. F. Gmel. Nimble-Will; Drop-seed grass. I.

Panicum capillare L. Witch grass. IV.

Panicum dichotomum L. Forked panic-grass. III, IV.

Phleum pratense L. Timothy. III, IV, V.

Poa annua L. Low speargrass. III, IV, V.

Poa compressa L. Wire grass; English blue-grass. III, IV, V.

Poa pratensis L. Kentucky blue-grass. III, IV, V.

Secale cereale L. Rye. III.

Setaria glauca (L.) Beauv. III, IV.

Setaria viridis (L.) Beauv. III, IV, V.

Triticum sativum L. Wheat. III.

Cyperaceae—Sedge Family.

Carex cephaloidea Dewey. Thin leaved sedge. IV.

Carex digitalis Willd. Slender wood sedge. II.

Carex granularis Muhl. Meadow sedge. III, IV.

Carex laxiflora Lam. Loose-flowered sedge. I, II.

Carex laxiflora var. *latifolia* Boott. White bear sedge.
I, II.

Carex plantaginea Lam. (Jones.)

Carex rosea Schkuhr. Yellow sedge. II.

Carex Shortiana Dewey. Short's sedge. Edge of I.

Carex straminea Willd. Straw sedge. IV.

Carex triceps Michx. Hirsute sedge. IV.

Carex vulpinoidea Michx. Fox sedge. IV.

Araceae—Arum Family.

Arisaema triphyllum (L.) Schott. Indian turnip. I, II.

Juncaceae—Rush Family.

Juncus tenuis Willd. Slender yard rush. III.

Liliaceae—Lily Family.

Asparagus officinalis L. Garden asparagus. III, IV.

Medeola virginiana L. Indian cucumber-root. II.

Ornithogalum umbellatum L. Star of Bethlehem. V.

Polygonatum biflorum (Walt) Ell. Small Solomon's Seal. II.

Polygonatum commutatum (R & S) Dietr. Great Solomon's
seal. II.

Smilacina racemosa (L.) Desf. False spikenard. II.

Smilax herbacea L. Carrion flower. I.

Smilax rotundifolia L. Greenbrier. I, II.

Tulipa gesneriana L. Common tulip. Near Marsh Hall.

Uvularia perfoliata L. Mealy bellwort. I.

Yucca filimentosa L. Yucca. IV.

Dioscoreaceae—Yam Family.

Dioscorea villosa. Wild Yam-root. I.

Iridaceae—Iris Family.

Sisyrinchium gramineum Curtis. Blue-eyed grass.

Orchidaceae—Orchid Family.

Orchis spectabilis L. Showy orchid. I.*Spiranthes gracilis* (Bigel) Beck. (Jones.)

Salicaceae—Willow Family.

Populus alba L. Silver leaved poplar. III.*Populus deltoides* Marsh. Cotton-wood. V.*Salix discolor* Muhl. Pussy willow. Talbot Hall.

Juglandaceae—Walnut Family.

Carya cordiformis (Wang) K. Koch. Bitternut. I, II.*Carya ovata* (Mill) K. Koch. Shellbark hickory. I, II.*Juglans cinerea* L. Butternut; White walnut. II.*Juglans nigra* L. Black walnut. I, II, III, V.

Betulaceae—Birch Family.

Alnus glutinosa L. European alder. V.*Betula alba* L. Cut-leaved weeping birch. V.*Betula populifolia* Marsh. White birch. V.*Corylus avellana* L. European hazelnut. V.*Ostrya virginiana* (Mill) K. Koch. American hop-hornbeam. IV.

Fagaceae—Beech Family.

Castanea dentata (Marsh) Borkh. Chestnut. I, II.*Fagus grandifolia* Ehrh. Beech. I, II, III.*Quercus alba* L. White Oak. I, II.*Quercus bicolor* Willd. Swamp white oak. III.*Quercus coccinea* Muench. Scarlet oak. II, III.*Quercus macrocarpa* Michx. Burr oak. III.*Quercus pedunculata* Ehrh. English oak. III.*Quercus prinus* L. Chestnut oak. III.*Quercus rubra* L. Red oak. III.

Urticaceae—Nettle Family.

Celtis occidentalis L. Hackberry. I, II, V.*Humulus lupulus* L. Hop vine. IV, V.*Laportea canadensis* (L.) Gaud. Wood nettle. I.*Machura pomifera* (Raf.) Schneider. Osage orange. IV.*Morus rubra* L. Red mulberry. I, V, VI.*Parietaria pennsylvanica* Muhl. Pennsylvania pellitory. I, II.*Pilea pumila* (L.) Gray. Rich weed; clear weed. I, II.*Ulmus americana* L. White elm. I, II, III, IV, V, VI.*Ulmus fulva* Michx. Red elm. I, II, VI.

Polygonaceae—Buckwheat Family.

Polygonum aviculare L. Knot-grass; door weed. IV, V, VI.

- Polygonum Convolvulus* L. Black bindweed. IV, V
Polygonum Persicaria L. Lady's thumb. I.
Rumex acetosella L. Sheep sorrel. III, IV, V.
Rumex crispus L. Curly dock. III, IV, V.
Rumex obtusifolius L. Yellow dock. III, IV, V.
Phytolaccaceae—Pokeweed Family.
Phytolacca decandra L. Pokeweed. V.
Illecebraceae—Knotwort Family.
Anychia canadensis (L.) B.S.P. Forked chickweed. I, II.
Caryophyllaceae—Pink Family.
Agrostemma Githago L. Corn cockle. IV.
Arenaria serpyllifolia L. Thyme-leaved sandwort. V.
Cerastium vulgatum L. Mouse-ear chickweed. General.
Saponaria ociffinalis L. Bouncing Bet. IV.
Stellaria media (L.) Cyrill. Common chickweed. General.
Portulacaceae—Purslane Family.
Claytonia virginica L. Spring beauty. II, III, VI.
Ranunculaceae—Crowfoot Family.
Actaea alba (L.) Mill. White baneberry. I.
Anemonella thalictroides (L.) Spach. Wind flower. I, II.
Cimicifuga racemosa (L.) Nutt. Black cohosh. I.
Clematis virginiana L. Virgin's bower. III, IV.
Hepatica triloba Chaix. Round lobed hepatica. I.
Ranunculus abortivus L. Small flowered crowfoot. General.
Ranunculus acris L. Tall crowfoot. One plant in 1914. VI.
Ranunculus repens L. Creeping buttercup. I.
Magnoliaceae—Magnolia Family.
Liriodendron tulipifera L. Tulip tree. II.
Calycanthaceae—Calycanthus Family.
Calycanthus floridus L. Strawberry shrub. IV.
Anonaceae—Custard Apple Family.
Asimina triloba Dunal. Common Papaw. I.
Menispermaceae—Moonseed Family.
Menispermum canadense L. Moonseed vine. II, IV.
Berberidaceae—Barberry Family.
Berberis aquifolium Pursh. Mahonia. East end of Talbot Hall.
Berberis vulgaris L. European barberry. V.
Berberis Thunbergii DC. Japanese barberry. Entrances.
Caulophyllum thalictroides (L.) Michx. Blue cohosh. I.
Podophyllum peltatum L. Mayapple. I, II.

Lauraceae—Laurel Family.

Benzoin aestivale (L.) Nees. Spicebush. I.

Papaveraceae—Poppy Family.

Chelidonium majus L. Celandine. I.

Sanguinaria canadensis L. Bloodroot. I, II.

Fumariaceae—Fumitory Family.

Dicentra canadensis (Goldie) Walp. Squirrel corn. I.

Dicentra Cucullaria (L.) Bernh. Dutchman's breeches. I.

Cruiferae—Mustard Family.

Barbarea stricta Andr. Winter cress. II, III.

Barbarea vulgaris R Br. Yellow rocket. I.

Capsella Bursa-pastoris (L.) Medic. Shepherds' purse.
General.

Cardamine bulbosa (Schreb.) B. S. P. Spring cress. I.

Dentaria lacinata Muhl. Toothwort. I.

Draba verna L. Whitlow grass. VI.

Lepidium virginicum L. Wild peppergrass. I, II, III, IV,
V, VI.

Sisymbrium officinale (L.) Scop. Hedge mustard. III,
IV, V.

Crassulaceae—Orpine Family.

Sedum ternatum Michx. Stonecrop. I.

Saxifragaceae—Saxifrage Family.

Deutzia scabra Thunb. Deutzia. Around buildings.

Philadelphus coronarius L. Mock orange; syringa. Same.

Ribes Cynosbati L. Wild gooseberry. I.

Saxifraga virginiana Michx. Early saxifrage. II.

Platanaceae—Plane tree Family.

Platanus occidentalis L. Sycamore tree. V.

Rosaceae—Rose Family.

Agrimonia gryposepala Wallr. Tall hairy agrimony. II.

Crataegus Crus-galli L. Cockspur thorn. VI.

Crataegus punctata Jacq. Large-fruited thorn. II.

Fragaria virginiana Duchesne. Strawberry. II, IV, V.

Geum canadense Jacq. White avens. II.

Geum vernum (Raf.) T & G. Spring avens. I, II, III.

Keria Japonica DC. Japanese Rose. Entrances.

Potentilla argentea L. Silvery cinquefoil. III.

Potentilla canadensis L. Fivefinger. II, III, IV.

- Prunus americana* Marsh. Wild plum. II.
Prunus avium L. Sweet cherry. IV.
Prunus serotina Ehrh. Wild black cherry. I, II, III, IV, V.
Pyrus Aucuparia Ehrh. European mountain ash. III.
Pyrus communis L. Pear. III.
Pyrus Japonica Thunb. Japanese Quince. VI.
Pyrus malus L. Apple. III, IV, V.
Rhodotypos kerrioides Sieb. False Kerria. Entrances.
Rosa multiflora Thunb. Rambler rose. Entrances and V.
Rosa rubiginosa L. Sweetbrier. V.
Rosa Rugosa Thunb. Entrances.
Rosa setigera Michx. Prairie rose. Entrances.
Rosa wichuraiana Crepin. Memorial rose. Entrances.
Rubus allegheniensis Porter. Blackberry. I, II, III, V.
Rubus occidentalis L. Black raspberry. I, II, III, V.
Rubus odoratus L. Purple-flowering raspberry. East entrance.
Rubus villosus Ait. Dewberry. III.
Spiraea bumalda Burvenich; var. *Anthony Waterer*. Crimson Spirea. Marsh.
Spiraea Douglassi Hook. Douglas' Meadowsweet. Near buildings.
Spiraea Thunbergii Sieb. Snow Garland. Marsh Hall.
Spiraea Van Houttei Zabel. Bridal wreath. Abundant along drives.

Leguminosae—Pulse Family.

- Amorpha fruticosa* L. False indigo. V.
Amphicarpa monoica (L.) Ell. Hog peanut. I.
Cercis canadensis L. Redbud. V.
Cladrastis lutea (Michx. f.) Koch. Yellow wood. I.
Desmodium canescens (L.) DC. Hoary tick-trefoil. I, II, III, IV, V.
Desmodium grandiflorum (Walt.) DC. Pointed-leaved tick-trefoil. I, II.
Gleditsia triacanthos L. Honey locust. II, III.
Gymnocladus dioica (L.) Koch. Kentucky coffee tree. I, IV.
Melilotus alba Desr. White sweet clover. III, IV, V.
Robinia Pseudo-Acacia L. Black locust. II, V.
Trifolium hybridum L. Alsike clover. III, IV, V.
Trifolium pratense L. Red clover. II, III, IV, V.

- Trifolium procumbens* L. Yellow hop-clover. III, IV, V, VI.
Trifolium repens L. White clover. General in the open.
- Oxalidaceae—Wood sorrel Family.
Oxalis stricta L. Yellow wood sorrel. General.
Oxalis violacea L. Violet wood sorrel. I.
- Geraniaceae—Geranium Family.
Geranium maculatum L. Cranesbill. I, II.
- Euphorbiaceae—Spurge Family.
Acalypha virginica L. Three-seeded mercury. General in shade.
Euphorbia maculata L. Spotted spurge. South hill.
- Anacardiaceae—Cashew Family.
Rhus copallina L. Dwarf sumac. IV.
Rhus cotinus L. Smoke tree. V, VI.
Rhus glabra L. Smooth sumac. II, III.
Rhus Toxicodendron L. Poison ivy. I, II, III, IV.
- Celastraceae—Staff tree Family.
Celastrus scandens L. Bittersweet, Wax work. I, II, III.
Evonymus atropurpureus Jacq. Wahoo. II, VI.
Evonymus radicans Sieb. Jap. spindle bush. Entrance and south plaza.
- Staphyleaceae—Bladdernut Family.
Staphylea trifolia L. American bladdernut. I.
- Aceraceae—Maple Family.
Acer Ginnala Max. Tartarian maple. VI.
Acer negundo L. Box elder. II, IV, V.
Acer palmatum Thunb. Japanese Maple. IV.
Acer palmatum var. *ornatum*, Carr. Cut-leaved Japanese Maple. IV.
Acer palmatum var. *reticulatum*, André. IV.
Acer platanoides L. Norway maple. Two forms. IV.
Acer rubrum L. Red maple. VI.
Acer saccharinum L. Silver maple. III, IV, VI.
Acer saccharum Marsh. Sugar maple. I, II, III, VI.
- Sapindaceae—Soapberry Family.
Aesculus glabra Willd. Ohio buckeye. I.
Aesculus Hippocastanum L. Horse chestnut. V.
- Balsaminaceae—Touch-me-not Family.
Impatiens biflora Walt. Jewel weed. I.
Impatiens pallida Nutt. Pale touch-me-not. I.

Rhamnaceae—Buckthorn Family.

Rhamnus cathartica L. Common buckthorn. V.

Vitaceae—Vine Family.

Ampelopsis tricuspidata Sieb. & Zucc. Boston ivy. On buildings.

Psedera quinquefolia (L.) Greene. Woodbine ivy. I, II, VI.

Vitis vulpina L. Frost grape. I, II.

Tiliaceae—Linden Family.

Tilia americana L. Basswood; Linden. I, II.

Tilia heterophylla Vent. White basswood. III.

Malvaceae—Mallow Family.

Althaea rosea Cav. Hollyhock. IV.

Hibiscus syriacus L. Shrubby althaea. VI.

Malva rotundifolia L. Common mallow, Cheeses. III, IV, V, VI.

Hypericaceae—St. John's-wort Family.

Hypericum punctatum Lam. Spotted St. John's-wort. II, IV, V.

Hypericum mutilum L. Small flowered St. John's-wort. IV, V.

Violaceae—Violet Family.

Viola papilionacea Pursh. Common blue violet. General.

Viola pubescens Ait. Downy yellow violet. I, II.

Viola rostrata Pursh. Long-spurred violet. I.

Elaeagnaceae—Oleaster Family.

Elaeagnus argentea Pursh. Silver berry. V.

Elaeagnus angustifolius (L.) var. *Spinosa*, Dipp. Oleaster. East entrance.

Onagraceae—Evening Primrose Family.

Circaea lutetiana L. Enchanter's nightshade. I, II.

Oenothera biennis L. Common evening primrose. III, IV, V.

Araliaceae—Ginseng Family.

Aralia racemosa L. Spikenard. I.

Aralia spinosa L. Hercules' club. VI.

Hedera helix L. English ivy. Marsh Hall.

Panax quinquefolium L. Ginseng. Found in I as late as 1914.

Umbelliferae—Parsley Family.

- Cryptotaenia canadensis* (L.) DC. Honewort. I, II.
Daucus Carota L. Wild carrot. General in the open.
Osmorhiza Claytoni (Michx.) Clarke. Sweet cicely. I.
Sanicula canadensis L. Short-styled snakeroot. I, II.
Sanicula trifoliata Bicknell. Large fruited snakeroot. I.

Cornaceae—Dogwood Family.

- Cornus alba*, var. *siberica*.
Cornus florida L. Flowering dogwood. I, II, V.
Cornus Mas L. Cornelian cherry. V.
Cornus stolonifera, Michx. Red-osier dogwood. V.
Nyssa sylvatica Marsh. Sour gum. I, II.

Ericaceae—Heath Family.

- Monotropa uniflora* L. Indian pipe. I.

Primulaceae—Primrose Family.

- Lysimachia quadrifolia* L. Whorled loosestrife. II.

Oleaceae—Olive Family.

- Chionanthus virginica* L. Fringe tree. V.
Forsythia suspensa Vahl. Goldenbell. East entrance.
Forsythia viridissima Linde. Goldenbell. East entrance.
Fraxinus americana L. White ash. I, II, III.
Fraxinus quadrangulata Michx. Blue ash. I.
Syringa vulgaris L. Common lilac. Near buildings.

Apocynaceae—Dogbane Family.

- Vinca minor* L. Periwinkle. I and on open hillsides.

Asclepiadaceae—Milkweed Family.

- Asclepias purpurascens* L. Purple milkweed. IV.
Asclepias syriaca L. Common milkweed. III, IV, V.
Asclepias tuberosa L. Butterfly weed. (Jones.)

Hydrophyllaceae—Waterleaf Family.

- Hydrophyllum appendiculatum* Michx. Appendaged waterleaf. I.
Hydrophyllum macrophyllum Nutt. Large-leaved waterleaf. I.

Boraginaceae—Borage Family.

- Lithospermum arvense* L. Corn gromwell. III.

Labiatae—Mint Family.

- Agastache nepetoides* (L.) Ktze. Giant hysop. I.
Agastache scrophulariaefolia (Willd.) Ktze. Figwort hysop. I.
Hedeoma pulegioides (L.) Pers. American pennyroyal.
 II, III.

- Lamium amplexicaule* L. Henbit dead-nettle. III.
Lamium purpureum L. Red deadnettle. II, III.
Leonurus Cardiaca L. Catnip. IV, VI.
Prunella vulgaris L. Self-heal. General.
- Solanaceae—Nightshade Family.
Physalis pubescens (L.). Low hairy ground-cherry. IV.
Physalis Virginia Mill. Virginia ground-cherry. IV.
Solanum Dulcamara L. Bittersweet. I, V.
Solanum nigrum L. Black nightshade. IV.
- Scrophulariaceae—Figwort Family.
Linaria vulgaris Hill. Butter and eggs. III, IV, V.
Verbascum Thapsus L. Mullein. III, IV, V.
Veronica arvensis L. Corn speedwell. General in the open.
Veronica peregrina L. Purslane-leaved veronica. General.
Veronica serpyllifolia L. Thyme-leaved veronica. General.
- Orobanchaceae—Broom-rape Family.
Epifagus virginiana (L.) Bart. Beechdrops. I, II.
- Bignoniaceae—Bignonia Family.
Catalpa bignonioides Walt. Catalpa. V, VI.
Tecoma radicans (L.) Juss. Trumpet creeper. IV, VI.
- Phrymaceae—Lopseed Family.
Phryma Leptostachya L. Lopseed. I.
- Plantaginaceae—Plantain Family.
Plantago lanceolata L. Ribwort; English plantain. General.
Plantago major L. Greater plantain. General.
Plantago Rugellii Dene. Rugel's Plantain. General.
- Rubiaceae—Madder Family.
Galium Aparine L. Cleavers. General in shaded places.
Galium circaezans Michx. Wild licorice. II, III.
Galium concinnum T & G. Shining bedstraw. II.
Galium triflorum Michx. Fragrant bedstraw. I, II.
Houstonia caerulea L. Bluets; Innocence. III.
Houstonia longifolia Gaertn. Long-leaved houstonia. III.
- Caprifoliaceae—Honeysuckle Family.
Diervilla grandiflora S & Z. Weigelia. Near buildings.
Lonicera japonica Thunb. Japanese honeysuckle. III, IV, V.
Lonicera sempervirens L. Coral honeysuckle. II.
Lonicera tartarica L. Tartarian honeysuckle. Entrances.
Lonicera Xylosteum L. European fly honeysuckle. V.
Sambucus canadensis L. American elder. II, IV, VI.

- Sambucus nigra* L. European elder. East plaza.
Symphoricarpos orbiculatus Moench. Coralberry. Entrances.
Symphoricarpos racemosus Michx. Snowberry. Entrances.
Viburnum prunifolium L. Black haw. II.
 Valerianaceae—Valerian Family.
Valerianella radiata (L.) Dufr. Beaked corn salad. IV.
 Dipsacaceae—Teasel Family.
Dipsacus sylvestris Huds. Teasel. III.
 Campanulaceae—Blue bell Family.
Specularia perfoliata (L.) A. DC. Venus's Looking-glass.
 II, III.
 Lobeliaceae—Lobelia Family.
Lobelia inflata L. Indian tobacco. III, IV.
Lobelia spicata Lam. Pale spiked lobelia. II.
 Compositae—Composite Family.
Achillea Millefolium L. Yarrow. General in the open.
Ambrosia artemisiifolia L. Common ragweed. General.
Ambrosia trifida L. Tall ragweed. II, IV, V.
Antennaria plantaginifolia (L.) Richards. Plantain-leaved
 everlasting. III.
Anthemis Cotula L. May weed. IV.
Arctium Lappa L. Burdock. III, IV, V, VI.
Aster cordifolius L. Blue wood aster. Common.
Aster ericoides L. White heath aster. III, IV, V.
Aster novae anglicae L. New England aster. III.
Bidens bipinnata L. Spanish needles. II.
Bidens frondosa L. Beggar-ticks. General.
Chrysanthemum Leucanthemum L. White daisy. III.
Cirsium lanceolatum Hill. Common bull thistle. IV, V.
Erigeron annuus (L.) Pers. Sweet scabius. General in the
 open.
Erigeron canadensis L. Horseweed. General.
Erigeron Philadelphicus L. Philadelphia fleabane. General.
Eupatorium urticaefolium Reichard. White snakeroot. I.
Gnaphalium polycephalum Michx. Sweet everlasting. III,
 IV.
Hieracium venosum L. Rattlesnake weed, II.
Lactuca canadensis L. Wild lettuce. III, IV, V.
Lactuca scariola L. Prickly lettuce. III, IV, V.
Prenanthes altissima L. Tall white lettuce. I, II.

- Senecio aureus* L. Golden ragwort. II, III.
Solidago caesia L. Wreath goldenrod. II, I.
Solidago juncea Ait. Early goldenrod. III.
Solidago rugosa Mill. Tall hairy goldenrod. III, IV.
Solidago serotina Ait. Late goldenrod. III, IV.
Taraxacum officinale Weber. Dandelion. General.
Vernonia altissima Nutt. Ironweed. III, IV, V.

Summary:

Families 74.

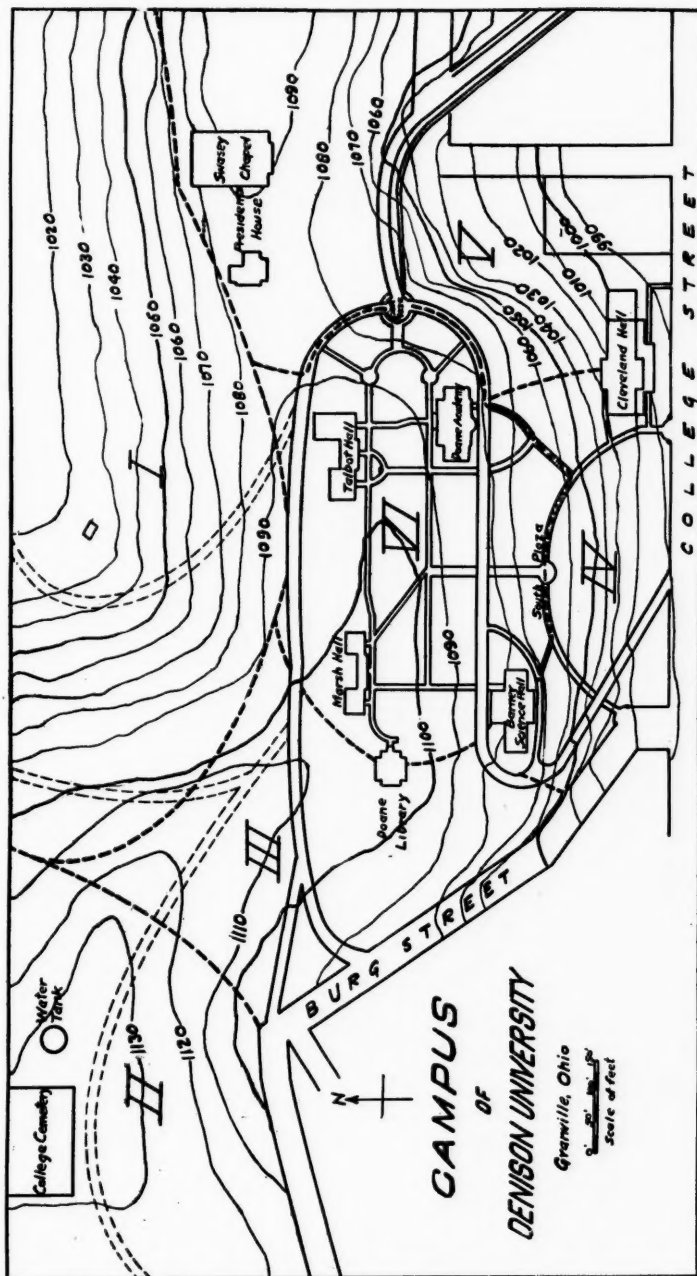
Genera 210

Species 321

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PLATE XVII
PLAN OF THE DENISON CAMPUS, SHOWING BOTANICAL AREAS



DWIGHT MUNSON MOORE

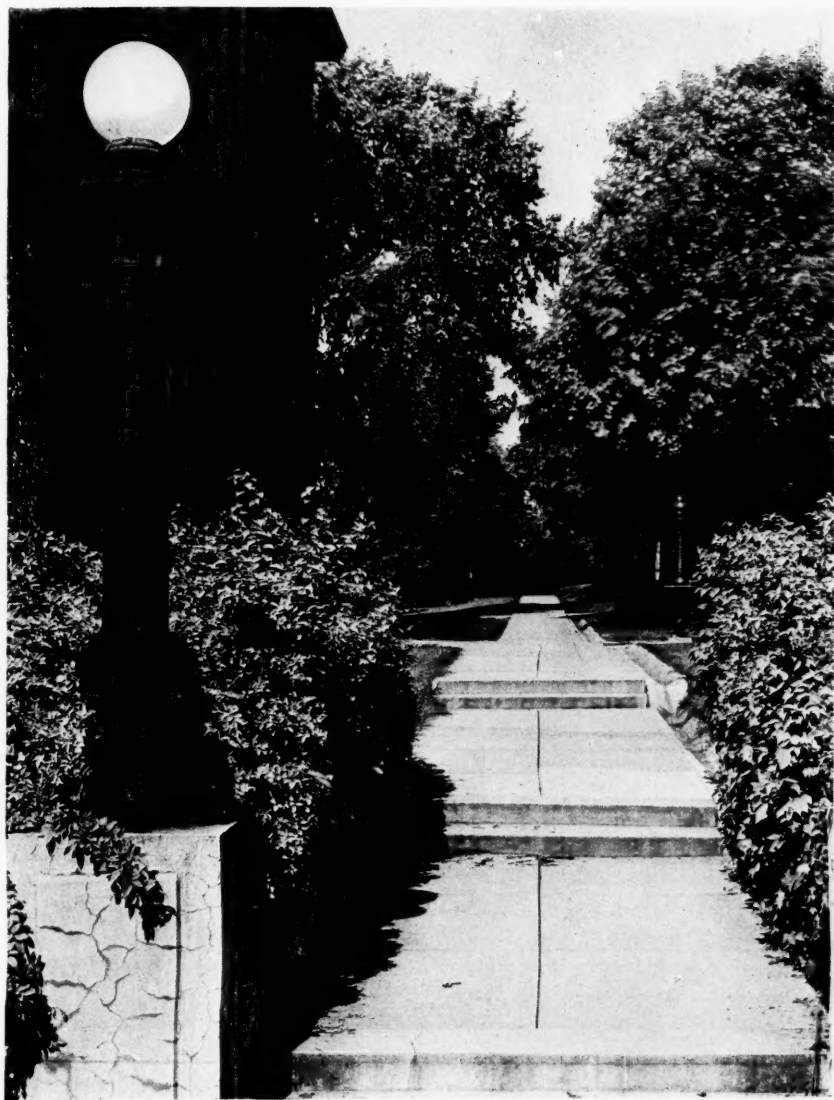
SURVEY OF CAMPUS OF DENISON UNIVERSITY

PLATE XVIII
THE NORTH WOOD WITH HYDROPHYLLUM IN BLOOM



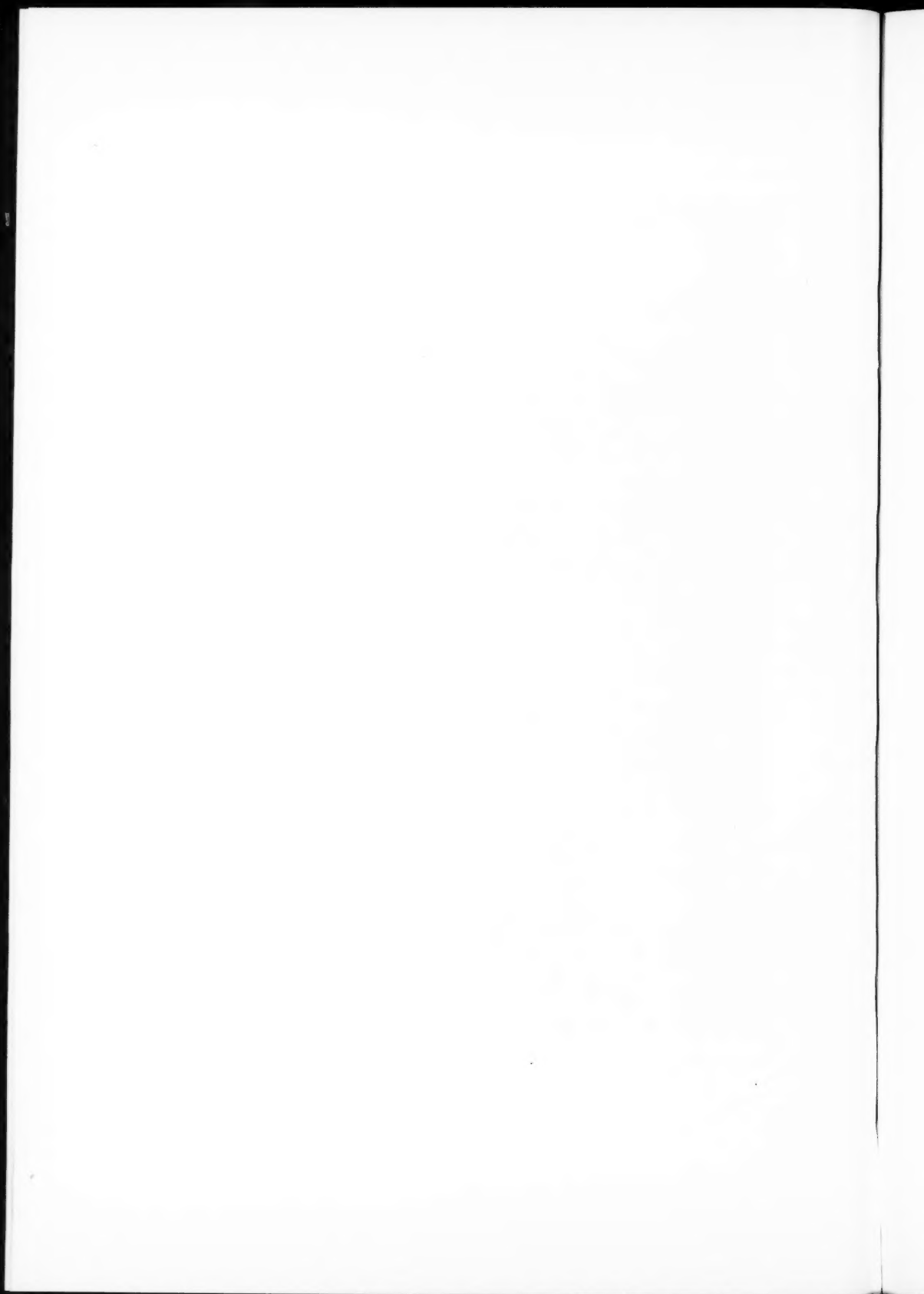
DWIGHT MUNSON MOORE SURVEY OF CAMPUS OF DENISON UNIVERSITY

PLATE XIX
SHRUBBERY FLANKING THE WALK LEADING TO DOANE ACADEMY BUILDING



DWIGHT MUNSON MOORE

SURVEY OF CAMPUS OF DENISON UNIVERSITY



THE UNDERGROUND MIGRATION OF OIL AND GAS

THE PROBLEM

KIRTLEY F. MATHER

A necessary antecedent to the flow of oil or gas in commercial quantities into a drill hole is the concentration of a considerable amount of volatile hydrocarbons in a small space under conditions suitable to its ready release. There is much evidence for the belief that a very great percentage of the world's petroleum and natural gas has originated in the midst of finely divided sediments, the muds, oozes, clays and shales. It is also apparent that oil and gas wells, with few exceptions, derive their valued products from the midst of comparatively coarse-grained sands and sandstones or from the larger crevices of limestones and shales. Disseminated broadly through fine grained sediments, the hydrocarbons are valueless, except in so far as they may be removed by expensive treatment of the rocks. Concentrated in limited portions of sand or sandstone, these same compounds become one of the most valuable sources of energy and power available to man. The history of oil and gas particles from the time of their origin to the moment when they enter the casing of a well is not only interesting; a knowledge of it is essential to the application of geology to the oil and gas industry. The ability to determine the probable location of new fields in advance of drilling and the most favorable directions of extension of existing fields depend on a clear understanding of the laws governing the movement of hydrocarbons through the rocks and of the conditions which control the action of those laws.

This movement seems to comprise two phases, of differing nature and presumably therefore resulting from different causes. The first of these is the migration of oil and gas out of the fine-grained source rocks into the coarser-grained sediments. This results in the segregation of the available hydrocarbons in "sands."

It may be conveniently referred to as *transverse migration*, for the direction of movement is in general across the bedding planes of the rocks from one stratum to another. The second phase involves the concentration of mobile hydrocarbons in certain areas within the extent of the more porous beds. It must depend upon lateral movement of the oil and gas within a stratum or series of strata and may be called *parallel migration*, for the direction of movement is more or less parallel to the bedding planes. Both sorts of movement are involved in the origin of most accumulations of oil or gas of economic value.

Before drawing any conclusions as to the probable causes of these migrations in any particular case, it will be well to review all possible motive forces which may have been in any way responsible. Having assembled the data it will then be less difficult to select the more important agents and observe how they may have coöperated in the local accumulation of oil or gas.

THE MOTIVE FORCES

Strictly speaking, there are but two forces which in the last analysis may be the ultimate causes of underground migration of fluids or vapors; these are (a) gravitational force and (b) molecular force. Both of these forces, however, may operate in several ways. The direct action of either may affect oil and gas indirectly through a long chain of intermediate causes and results. Interaction and reaction between the two introduce a number of complications. A somewhat arbitrary grouping of the many proximate causes of migration must therefore be adopted.¹

Induration of sediments

The genesis of oil and gas depends upon the entrapping of plant and animal tissue in the midst of accumulations of inorganic debris, which whether deposited by water or by wind, are at first loosely heaped together. The consolidation of fragmented

¹ For a classification of causes of oil migration different from that adopted here, see V. Zeigler, *The Movements of Oil and Gas Through Rocks*, Economic Geology, vol. 13, pp. 335-348, 1918.

material into "rocks," as that term is popularly used, is accompanied, at least in part, by the conversion of organic substances into bitumens. Both processes involve, or may involve, transition through a number of stages, none of which is separated from its neighbors by hard and fast subdivisions either in time or in space. Induration of sediments, and distillation of oil and gas progress simultaneously from the time of deposition on sea or lake floor or along the river flood plain. Each affects the other, sometimes favorably, sometimes adversely; but most important is the influence which induration of sediments has upon the location of the products of distillation. For purposes of analysis it is convenient to consider the processes of consolidation of fragmented material into "solid rock" under two heads: (1) compacting of sediments, (2) cementation of sediments. As a matter of fact, of course, the two processes may proceed more or less simultaneously.

Compacting of sediments

Much information of great importance to petroleum geologists concerning the consolidation of sedimentary material is wanting. Careful observations of the changes now going on beneath the shallow water of marginal seas are needed to make possible accurate interpretation of the results of similar changes which have taken place in the past. Such studies have been made by few, but will doubtless become a more important part of the education of the geologist of the future.

Sediments deposited by moving water must be at first loosely heaped on the basin floor; pore space is at a maximum; open spaces are filled with water. With increase of burden due to continual deposition of debris the loose accumulation must settle and be compressed into smaller dimensions. Shrinkage of volume beneath the weight of the overlying debris may greatly reduce the thickness of the accumulations. Shaw² reports, for example, that the shore of the Mississippi delta "is in places

² E. W. Shaw, The mud lumps at the mouths of the Mississippi; U. S. Geol. Survey, Prof. Paper, 85-B, pp. 11-27, 1913.

actually retreating, not so much by sea erosion as by settling, which in places predominates over upbuilding." This compacting of material must necessarily squeeze out fluids from the dwindling pores.

Sedimentary debris comprises three classes of material, clay particles, sand grains, and calcareous fragments, distinguished on the basis of composition and shape of individual particles rather than on the basis of size. Theoretically there should be an equal amount of compacting of earthy materials of the same composition and individual shape, under the same weight of overburden and with an equal time for adjustment, regardless of the dimensions of the the particles. Such classifications according to size as that of the Bureau of Soils, which applies the term sand to all earthy materials with dimensions between 0.05 and 1.0 mm., the term silt to those between 0.005 and 0.05 mm., and the term clay to all particles less than 0.005 mm. in diameter, are of value in this connection merely because they are also more or less perfect classifications according to chemical and mineral composition and therefore according to shape. Silt and clay particles are in a large degree tabular in shape, so they may fit together, like bricks in a wall, with small and few voids between them. Resistance to crushing of individual flakes is comparatively slight, so that flakes which do not assume approximately parallel orientation are broken and the fragments pushed into the proper plane. Sand grains, on the contrary, are roughly equidimensional or spheroidal in shape, so that they must fit together, like field stones in rubble-work, with large interstices between them. Crushing strength of individual grains is proportionally very much greater. Consequently, in any bedded deposit of interstratified clay and sand, the compacting of the clay strata is many times as great as that of the sand layers, and because reduction of pore space is proportional to amount of compacting, fluids will be squeezed from the midst of the clay much more completely than from the voids in the sandy beds. Calcareous debris would probably be intermediate between clay and sand in its reaction to compacting stresses.

Beyond doubt, the first stages of formation of organic material into bitumens are contemporaneous with burial in the silt or ooze of the basin floor. Synthesis of oil and gas is at a maximum in the midst of muds and silts, and is at a minimum in sandy beds. Compacting of the former drives out the fluids and gases to a great extent. Some of these escape upward into the water or air above the accumulating sediments, but much of them must first pass through the pores and openings of interbedded sandy layers. Here differential surface tension and viscosity tend to hold the newly formed petroleum, and may effectively segregate it in the coarser beds. Thus at the very start of the process of oil formation this transfer of oil from its place of origin in the muds to its place of storage in the sands begins.

Continued accumulation of debris in the lodgment basin means deeper burial and increased compactness of the successive strata. More and more of the fluid content of the muds and shales is forced out, and more impenetrable become the overlying strata which prevent the escape of the increasing volume of oil or gas from the sandy reservoirs into which it has been driven. Eventually the muds, silts, and clays become shale and the sands become sandstone. Loose debris is now "solid rock" and compacting of sediments becomes henceforth a quantitatively minor matter. Shale and sandstone alike acquire sufficient rigidity and strength to support the weight of a considerable thickness of overburden.

Nevertheless, compacting does not entirely cease when the sediments are consolidated into "rocks." Somewhere below the surface is a zone below which voids cannot exist within the rocks; deformation there takes place by rock flowage rather than by rock fracture. The thickness of overburden necessary to produce sufficient pressure to close all openings is generally believed to be about eleven miles, and the notion is prevalent that a "zone of flow" exists at some such depth as that. It should be noted, however, that the eleven-mile column is necessary to deform the *strongest* rocks, while the weaker rocks will "flow" under much less pressure. The "zone of flow" is not a true "zone," but a condition in which different rocks are found

at vastly different depths below the surface. Indeed it would in most cases be extremely difficult if not impossible to draw a line between compacting of sediments and rock flow; the one grades imperceptibly into the other. The "zone of flow" is almost at the surface for certain materials, among which the most conspicuous are the mud rocks which are pre-eminently the birthplace of petroleum. The Mississippi Delta, according to Shaw,³ seems to be affected by "a bodily flowage toward the sea." In places the Delta front is bulging outward and upward as the materials of which it is composed flow laterally after having been compacted by the weight of the shallow overburden.

Such flowage of the rocks may further the process of transfer of petroleum from shales to sandstone or to limestone, but is probably much less important than the universal compacting which necessarily must result from the accumulation of any considerable amount of sediment in any lodgment basin. The movement, both of solids and of fluids, which must accompany rock flow may greatly expedite the segregation of oil and gas by other processes to which reference is made in the succeeding paragraphs. In general, simple compacting precedes rock flow and decreases in importance as the later process increases in amount, but no sharp distinction may be drawn either between the processes or their results.

Cementation of sediments

Consolidation of sediments is not solely nor indeed principally a matter of compacting; especially are the constituents of sandy strata bound together by interstitial cement. Cementation may begin immediately after the rocks are subjected to the action of ground water. It is through cementation that sands become sandstone, and sandstones become quartzite. Obviously, the greater the amount of precipitated cements the less the effective pore space of the rock. If cementation commences along a definite plane or at a point and proceeds regularly

³ Loc. cit., pp. 17, 18.

outward, it will necessarily exclude ground water, oil, or gas, from the pores which it closes and may drive fluids and gases into other portions of the reservoir. The distinction between the sands reported by the driller as tight (and dry) and those stated to be loose (and water, gas, or oil-bearing) is probably in most cases a result of differential cementation.

At present, however, it is impossible to say whether a tight sand is devoid of oil because the cementation of the sand drives out its fluid content or because the presence of cement filling the pores prevented the immigration of valued hydrocarbons; probably the latter is more often the case. In general, it should be observed that the presence of oil in a rock pore will itself hinder if not entirely prevent the filling of that pore by cement carried in aqueous solutions. Between the encroaching cement and the retreating oil there must always be a buffer of water. It is doubtful whether progressive cementation of sediments has even been an important cause of the migration of oil or gas.

Capillary action

Molecular forces are by no means completely understood. The exact nature of both inter-molecular and intra-molecular attractions and repulsions are more or less of a mystery. The best that can be done in the present state of knowledge is to give names to the more obvious phenomena resulting from these forces, and to postpone the enquiry as to their fundamental causes until the physicist and the chemist have completed their research concerning them.

Of the phenomena attributable to molecular action, the two most important in this connection are capillarity and surface tension. Surface tension is the property "which exists in the surface film of all liquids and tends to bring the contained volume into a form having the least superficial area." It is this property which causes small quantities of oil, water, mercury, or other fluids to form into spherical "drops" when scattered over the surface of a solid or sprayed into the air. It apparently results from cohesion, the attraction existing between closely adjacent molecules of the same substance, a force which is "quite

insensible between two portions of matter separated by any distance which we can directly measure." Consequently within a liquid body each molecule which is more than about the twenty-thousandth part of a millimeter distant from the surface is affected equally on all sides by cohesion with other molecules which surround it. But the molecules in the surface film are on the whole attracted inward, and tension results. The amount of this tension depends upon the curvature of the surface, the composition and temperature of the liquid, and the nature of the surrounding medium or media.

Capillarity⁴ is "the action by which the surface of a liquid, where it is in contact with a solid is elevated or depressed." Because of it the surface of the water in a glass is not plane but is curved upward around the margins, and for the same reason the top of the mercury column in a thermometer is convex upward instead of flat. But the phenomenon is best observed when liquids enter tubes or spaces of small diameter or width, for then it may cause the liquid to move in a direction quite contrary to that in which it would be impelled by gravity. The absorption of a drop of ink by blotting paper in which the tiny air spaces between the paper fibers draw the fluid upward, or the continual supply of oil through the wick of the kerosene lamp, which keeps the flame steadily burning several inches above the oil reservoir, are familiar illustrations. Capillarity is in part a result of surface tension but depends also upon the forces of adhesion, forces which act between closely adjacent molecules of unlike substance, those of the liquid and of the containing solid.

Capillary action may best be considered as operating in tubes of small diameter or in fissures of minute width. Openings into which a liquid is drawn with a force greater than that exerted by gravity may be referred to as capillary openings. In such openings the mean height to which the fluid rises varies inversely as the radius of the tube or the width of the fissure. The capil-

⁴For a clear exposition of capillarity see J. C. Maxwell's article "Capillary Action," revised by Lord Raleigh, in *Encyclopædia Britannica*, eleventh edition, 1910.

lary pull also varies with the surface tension of the fluid and is at once affected by any change in surface tension. A water-air surface at ordinary temperatures has a tension of 70 to 75 dynes per square centimeter, and so far as water is concerned, all tubes of diameter less than 0.508 mm., and all smooth fissures less than 0.254 mm. wide are capillary. According to Washburne,⁵ "a salty water, such as that commonly found in oil fields, having a density of 1.14 at 20°C., would have a surface tension of about 79 dynes per centimeter," while Pennsylvania crude oil with a specific gravity of 0.852 displayed a surface tension of only 24.1 dynes per centimeter at 20°C. The same author is responsible also for the statement "that all crude oils have low surface tension, probably in the neighborhood of 25 dynes, except only the oils that have lost all of their light constituents, which are of no consequence in problems of deep migration." Because of their low surface tension, only those tubes with a diameter of less than about 0.25 mm., and fissures not over 0.13 mm. wide are capillary openings with respect to the average crude oil.

Surface tension decreases with increase in temperature and becomes zero at the critical temperature of each substance; capillary action is therefore limited to the outer shell of the earth and cannot be operative at great depths where temperatures are high. "The effect of pressure on surface tension (and therefore upon capillary action) is unknown, but is presumably small."⁶

Finally in summing up these physical factors concerning capillarity, it should be noted that although capillary action may draw fluids into small passageways within the rocks it cannot of itself induce continued flow through these passageways. Since it is an expression of surface tension, capillarity is operative "only when there is a free liquid surface within the capillary." Once the capillary opening is filled with liquid, capillary action ceases, unless perchance another liquid of different surface tension approaches an opening of the tube.

⁵ C. W. Washburne, The capillary concentration of gas and oil, *Trans. Am. Inst. Min. Eng.*, vol. 50, pp. 829-858, 1915.

⁶ John Johnson and L. H. Adams, Observations on the Daubree experiment and capillarity in relation to certain geological speculation, *Journ. Geol.*, vol. 22, pp. 1-15, 1914.

Capillary action on crude oil in dry materials; experimental data

Dissemination through fuller's earth. Experiments conducted by David T. Day⁷ indicate that in spite of its relatively low surface tension crude oil disseminates rapidly in dry, finely divided material such as fuller's earth. Not only does oil rise directly against gravity to a height of 5 or 6 feet in a tube packed with fuller's earth, "but if the tube be sealed at the upper end the oil will still rise in the tube, driving out the air in the pores of the earth and compressing it in the upper part of the tube with a pressure sufficient to blow out the clay if the top of the tube be suddenly broken off and the air thus released."

No experimental data are available as to the exact size of the capillary spaces through which the oil is thus forced to migrate, but somewhat similar movement is known to take place through finely divided quartz sand and amorphous silica.⁸ More than likely the upper limit of pore sizes conforms to that suggested above as the theoretical dimensions of capillary openings for crude oil.

Effect of dissemination upon composition of crude oil. "When a glass tube is packed tightly with dry fuller's earth, and one end is allowed to stand for one or two days in crude petroleum the oil diffusing up through the clay fractionates to a considerable extent. Thus, when the upper fifth portion of the clay is dropped into water, a lighter gravity oil is driven out by the water. This first fraction is entirely colorless. The lower fractions are heavier and more and more highly colored. The bottom section may be almost solid, and is darker in color than the original oil. A fractionation by diffusion has been effected, which is similar to fractionation by distillation, but is not so complete."⁹ Richardson¹⁰ made similar tests with crude oil from Texas and found that sulphur compounds could be separated from that oil by their failure to migrate into fuller's earth.

⁷ David T. Day, The conditions of accumulation of petroleum in the earth, Am. Inst. Min. Eng., Trans., vol. 41, pp. 219-224, 1911.

⁸ David T. Day, Experiments on the diffusion of crude petroleum through fuller's earth, Science, N. S., vol. 17, pp. 1007-1008, 1903.

⁹ Day, loc. cit., p. 222.

¹⁰ Clifford Richardson, Journ. Soc. Chem. Ind., vol. 21, pp. 316-17, 1902.

Apparently "the size of the capillaries is of great consequence in these diffusion phenomena. Finely divided material, such as amorphous silica, has no observable fractionating-power on oils that are readily fractionated by dry clays." Quartz sands likewise exhibit practically no selective action, but dried shale of Devonian age proved to exert an action similar to that of fuller's earth.

As shown by Engler and others, there is no chemical change in this process; fractionation by capillary dissemination is merely a mechanical separation of slowly diffusing liquids from those which pass more rapidly into the capillary spaces.

Application to the conditions existing in the earth

Except in arid regions, the pores of all sedimentary rocks near the surface of the earth are more or less completely filled with water; but the deeper levels which have been penetrated by the drill in the Appalachian oil fields and elsewhere are apparently dry. Oil field waters will be discussed in a subsequent section of this paper; it is here only necessary to call attention to the fact that the amount of water found in the sedimentary rocks of most oil fields decreases with depth. In the Appalachian region "fresh water is found in appreciable amounts in one or more beds as a rule to a maximum depth of 200 to 800 feet. Brackish or salt water occurs below the fresh water at depths ranging from 400 to about 3000 feet. In a few wells out of the thousands drilled, salt water was found at greater depths than 3000 feet, but in all cases the amount and head of this water was very small, regardless of the porosity of the containing bed. In many wells open porous sandstones from 1000 to 3000 feet from the surface show no water. Many of these were found to take up, with surprising rapidity, water poured into the well in the process of drilling."¹¹ This is by no means equivalent to stating that shales three or four thousand feet below the surface of the earth are known to be dry, but it

¹¹ M. J. Munn, *The Anticlinal and hydraulic theories of oil and gas accumulations*, Econ. Geol., vol. 4, pp. 509-529, 1909.

strongly suggests the possibility that at some such depth certain of the finer grained sediments may be nearly or quite devoid of moisture. If so, oil entering or present in the small pores of these shales would be broadly disseminated throughout the rock by capillary action. This is just the opposite movement to that requisite for the accumulation of oil in economic quantities, but such migration may have been preliminary to certain processes of accumulation.

The influence of such capillary migration upon the composition of oils subjected to it is probably the only effect of quantitative importance to the oil industry. As suggested by Day, it is possible to explain the difference in the nature of the oil of different fields by the hypothesis "that dark colored oil (possibly containing sulphur and asphalt) entered shales varying in fractionating-power, due to varying porosity or moisture," and was there fractionated into oils of various colors and compositions. It is even possible, although in the opinion of the present writer scarcely probable, that the oils from the Carboniferous rocks of Pennsylvania and vicinity are "the same as the Ordovician limestone oils of Ohio, with the sulphur removed by diffusion." Furthermore, the long series of quantitative tests made by Gilpin and Cram¹² indicate that the paraffin hydrocarbons diffused farther than the unsaturated or asphaltic hydrocarbons which were consequently left behind in migration due to capillary attraction. The strong contrast between the paraffin oils of Pennsylvania and the asphaltic oils of California may be an illustration of the effect of capillary dispersal resulting in fractionation or filtration in the one case and the absence of this action in the other.

Differential capillarity of oil and water; experimental data

In the experiments conducted by Day, Gilpin and Cram, above referred to, in which crude oil was drawn upward by capillary action into tubes packed with dry fuller's earth, the

¹² J. E. Gilpin and M. P. Cram, The fractionation of crude petroleum by capillary diffusion, U. S. Geol. Survey, Bull. 365, 1908.

oil was later displaced from the earth by water. Fractions of the earth removed from the tube and dropped into water, rapidly gave up their content of oil, and the pores formerly occupied by oil became filled with water. Several experiments which approximate more closely the conditions existing within the earth have been described by McCoy,¹³ Mills,¹⁴ and Cook.¹⁵ In one of McCoy's experiments, an open glass cylinder was placed in a pan of wet sand, so that the sand filled the lower one-third of the cylinder. The water had free access from the sand in the pan to the sand in the cylinder. A layer of oil-saturated mud, made by adding Oklahoma crude oil (38°Beaume) to a mixture of dried clays, the particles of which measured from 0.005 to 0.001 mm., was placed in the cylinder upon the wet sand; this mud occupied about one-third of the cylinder and was above the level of the water in the pan. The cylinder was then filled with *dry* sand, and the top sealed with a tube attachment to a closed barometer. Within twenty-four hours, the water migrated upward about 1 cm. into the mud, and the oil moved about the same amount into the dry sand; some of the oil also migrated down into the wet sand and collected in the larger openings; the mercury rose in the closed barometer to a height of about 2.5 cm. above that corresponding to the atmospheric pressure. As thus described the experiment is essentially a modification of the Daubree experiment of 1861, in which water passed through sandstone against pressure,¹⁶ or of the "atmometer"¹⁷ which gives similar results. The most significant, obvious

¹³ A. W. McCoy, Some effects of capillarity on oil accumulation, *Jour. Geol.*, vol. 24, pp. 798-805, 1916; reprinted, *Bull. Southwestern Assoc. Petrol. Geolog.*, vol. 1, pp. 140-47, 1917.

¹⁴ R. V. A. Mills, Experimental Studies of subsurface relationships in oil and gas fields, *Econ. Geol.*, vol. 15, pp. 398-421, 1920.

¹⁵ C. W. Cook, Study of capillary relationships of oil and water, *Econ. Geol.*, vol. 18, pp. 167-72, 1923.

¹⁶ Daubree, *Etudes Synthetiques de Geologie Experimentale*, Paris, 1879, pp. 238.

¹⁷ J. Johnston and L. H. Adams, Observations on the Daubree experiment and capillarity in relation to certain geological speculation, *Jour. Geol.*, vol. 22, pp. 1-15, 1914.

result in the present connection is the downward migration of oil from the extremely small pores between the mud particles to the larger interstices between the sand grains, which had previously been filled with water.

In McCoy's second experiment, a layer of wet sand was arranged in the form of an anticline between two layers of oil saturated mud. The sand grains near the crown of the artificial anticline were small, all passing a 40 mesh sieve, while those on the limbs were coarser, none passing a 10 mesh sieve. The top of the rectangular glass box containing the three layers was sealed with paraffin and water allowed to enter through openings at the lowest horizon of the sand, but was kept at a level below the top of the curve in the sand. Water entered the mud both above and below the sand layer, and replaced about an inch of the oil in the mud. The displaced oil moved into the interstices between the coarser grains of sand and within 24 hours there was an "oil pool" in both limbs of the anticline on either side of its water-filled crest. These results could not have been effected by simple capillary pressure such as that operative in the Dabree experiment because the spaces between sand or mud particles were occupied with either oil or water and the paraffin seal over the top of the box prevented evaporation. There were, however, certain forces at work which drove oil out of small openings into large ones and at the same time drew water from the larger to the smaller pores, regardless of the direction involved in the transfer or of the tendency of oil to float on top of water.

In many of Mills' experiments, coarser sands were used, and water circulation, sometimes under considerable head, was involved. Few of them afforded much opportunity for capillary action to display itself. Nevertheless, capillary adjustments seem to have occurred between oil and water in saturated strata. These, states Mills, are restricted within short lateral ranges, amounting to only a few centimeters in his experiments. His conclusion was that the principal rôle of capillarity, in saturated strata, is to retard rather than to promote fluid movements.

Theoretical considerations

As stated above, the surface tension of crude oil is between one-third and one-half that of water. Capillary action must therefore exert a much stronger pull upon water than upon oil. According to Washburne,¹⁸

the amount of the capillary pull varies inversely as the diameter of a pore, hence the constant tendency of capillarity is to draw water, rather than oil, into the finest of openings, displacing any gas or oil in the latter. Gas itself is not drawn into capillaries by the action of surface tension, and it can leave the fine pores without any capillary resistance. It is therefore the most quickly and most completely gathered in the largest spaces available. Moreover, capillarity resists any movement of water from fine toward large pores more than it resists the movement of oil or gas in that direction. In short, water enters fine capillaries about three times as readily as oil, and it encounters about three times as much capillary resistance in leaving them.

The final result of this action must be the concentration of nearly all the gas and oil in the openings having least capillary power, namely, in fissures if present, and in the larger rock pores. This appears to be the general rule in oil fields, where the pores of the coarser-grained rocks contain practically all of the oil, while the pores of the adjacent fine-grained rocks contain practically no oil.

Here, too, is a possible explanation of the phenomena displayed in the experiments described above. Differential capillary attraction may be competent to induce the migration of water from larger pores into adjacent ones originally filled with oil and to force the oil out of these spaces into those originally occupied by water.

There is, however, a possible fallacy here.¹⁹ In comparing the surface tension of oil and of water, the comparison was between the tension on an oil-air surface and that on a water-air surface. In the experiments with saturated sediments, and presumably under most conditions obtaining within the earth,

¹⁸ C. W. Washburne, The capillary concentration of gas and oil, Trans. Am. Inst. Min. Eng., vol. 50, pp. 823-858, 1915.

¹⁹ Cf. Johnson, R. H., The Time Factor in the Accumulation of Oil and Gas, Bull. Am. Assoc. Petrol. Geologists, vol. 5, pp. 475-481, 1921.

it is the molecular forces operating on an oil-water surface which are significant. Here quantitative data are not available; Cook's tentative conclusion, that the minimum size of opening, which will allow the interchange of oil and water to occur, is considerably larger than the minimum which will permit the capillary movement of either oil or water alone, would suggest that the simple numerical ratio cited by Washburne does not directly apply.²⁰ Nevertheless, it is evidently a fact that under certain conditions this interchange of oil and water does take place exactly as though the movements were induced by capillary action. Probably, as Cook points out, the effects of differential adhesion of oil and water, especially the far superior adhesion of water for rock, are quantitatively more important than those resulting from differential cohesion of these same liquids as expressed by their surface tension. The phenomena of adhesion undoubtedly play an important part in capillary action and may be largely responsible for the interchanges of oil and water, which have been observed.

The direction of the movement resulting from such interchange is entirely independent of gravity; impelled by differential capillary forces, oil or gas may migrate upward or downward or laterally with equal facility. Migration would be from smaller to larger openings in the rocks, and presumably cannot reverse itself so long as water is present. Probably, neither oil nor gas can, under ordinary conditions, move into a stratum or portion of a stratum of rock which contains no openings of greater than capillary dimensions (for water) and is thoroughly saturated with water.

Application to the conditions existing in the earth

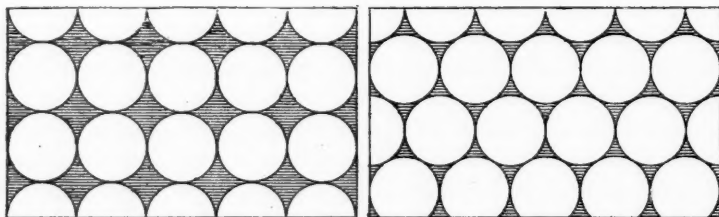
These considerations make evident at once the imperative necessity of data concerning the pore spaces existing in sedimentary rocks at different stages in their history. Not only should the total amount of pore space be known, but, of probably

²⁰ See also Skirvin, O. W., *Experimental Study of the Invasion of Oil into a Water-Wet Sand*, *Econ. Geol.*, vol. 17, pp. 461-469, 1922.

much greater importance, the size of the spaces in different kinds of rocks under different conditions should be determined.

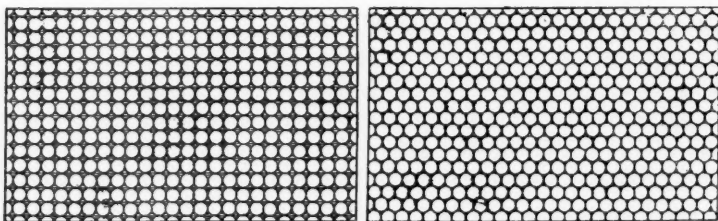
Porosity of sedimentary rocks. The total volume of pore space in a rock does not depend upon the size of the rock particles but upon their shape, assortment, arrangement, and degree of cementation. In figure 1, for example, the total amount of pore space in A and C, or B and D, is the same, but there is a progressive decrease in the diameter of the individual pores from the ideal case shown in A to that in D. Variations in the dimensions of interstices in clastic rocks must in general be roughly proportional to the size of rock grains, other things being equal. It is not, however, the average size of grain which is the most important consideration, but the proportion of extremely fine particles which if present in sufficient amount would "sift" into the larger spaces between the coarser grains and leave openings with dimensions approximating one-sixth to one-half the diameter of these smallest components of the rock. An argillaceous sand might, therefore, have pore spaces the dimensions of which would approximate those of the interstices between the particles of clay in shale. The more perfect the assortment by size and the "cleaner" the sand, the larger will be the voids in the rock. But this neglects the effect of cementation which as evidenced in diagrams E, F, and G, of figure 1, greatly influences the size of pore as well as the total amount of porosity. With these variables, it is readily apparent that abrupt changes in pore dimensions as well as in volume of openings may be expected in any sedimentary series when traced laterally or traversed vertically.

Data are not available for more than a broad approximation covering the relative sizes of pores in shales and sandstones. It is probable however, that interstitial spaces in most shales, are less than 0.01 mm. in diameter, and in the finer clay shales, especially if considerably compressed, openings would average less than a micron (the thousandth part of a millimeter) in cross-section. Sandstones display greater variation in size of pores because of the limitless variations in amount of cement and in abundance of fine constituents. The sands used by



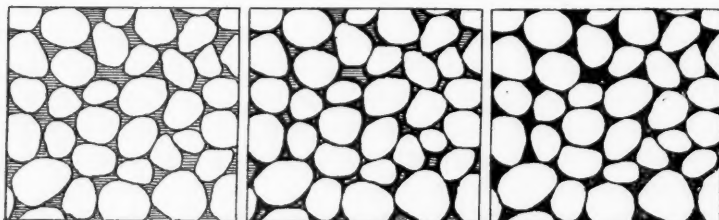
A. Hypothetical rock with large spherical grains, maximum pore space.

B. Hypothetical rock with large spherical grains, minimum pore space.



C. Hypothetical rock with small spherical grains, maximum pore space.

D. Hypothetical rock with small spherical grains, minimum pore space.



□ Sand grains ▨ Pore space ■ Cement

E. Irregular grains without cement, showing maximum pore space.

F. Irregular grains with interspaces partly filled with cement.

G. Irregular grains with interspaces completely filled with cement, no pore space.

FIG. 1. PORE SPACE OF ROCKS

(Reproduced with permission from Geological Survey of Kansas, Bull. 3, pl. III, 1917)

King²¹ in measuring the observed pore space in soil and rock are reported to have had an "approximate effective diameter" which varied from less than 0.1 mm. to more than 2.5 mm., with the greater number of samples approximating 0.2 and 0.3 mm. It is entirely out of the question to apply any rigid mathematical formula stating the relation between pore size and sand grain diameter. Irregularity of outline of the sand particles is so great in the average sandstone that the common assumption of an accumulation of spheres is scarcely an approximation to the truth. To assume that the grains are spheres gives neither the maximum nor minimum total porosity or size of pore. "For simple sands with angular grains the pore space is much larger than it is for the rounded sands of the same sizes of grains, and in the case of crushed glass, whose grains are more angular than those of the crushed limestone, which have a tendency to be cuboidal in form, the pore space is the largest of all."²² If this is true for total pore space, it must necessarily follow that the size of individual pores is greater in sandstones composed of angular grains than in those composed of rounded grains of similar sizes. The dimensions of occasional pores may equal the diameter of the sand grains if the latter are angular. The width of the open spaces between grains of ordinary sandstones may therefore vary from less than a micron to more than a millimeter. Probably the average pores of a poorly cemented sandstone would be between 0.1 and 0.5 mm. in width.

Transverse migration of oil and gas. In any series of alternating shales and sandstones, containing sufficient water to fill the openings in the shales, oil and gas will therefore tend to move from the shales and segregate in the sandstone strata. This transverse movement of the hydrocarbons will not be complete. In the first place there will almost certainly be porous lenses in the shale beds, entirely surrounded by compact shale with finer openings. Oil once driven into these lenses cannot afterward return into the finer peripheral pores as long as they are filled

²¹ F. H. King, Principles and conditions of the movements of ground water, U. S. Geol. Surv., 19th Ann. Rept., Pt. 2, pp. 59-294, 1899.

²² King, loc. cit., p. 215.

with water; hence it cannot traverse a zone of wet shale, all the openings in which are finer than those in which the oil occurs even though a coarsely porous sandstone may be only a few inches distant. In the second place, a considerable fraction of the oil will be retained in the argillaceous rocks by absorption and adhesion, as indicated by the experiments of Gilpin and Cram²³ who state "when oil is mixed with fuller's earth and then displaced with water, about one-third of the oil remains in the earth." These capillary forces would probably be most effective in their task of draining the shales of oil and gas and segregating these substances in the sandy beds if the latter were present at frequent intervals in the midst of a thick shale series. Recurrence of sandstones is more favorable than the same amount of sand deposited in a single massive bed, but in any event it is apparent that nothing could be more effective as a seal to stop transverse migration of either oil or gas than a water soaked bed of shale capping the sands. Once driven into the sandy horizons the hydrocarbons are there imprisoned, unless super-capillary fissures traverse the shales.

A consideration of the variability of dimensions of pore spaces in any sedimentary series makes it evident that migration of oil and gas due to capillary forces cannot in most cases extend over great distances. The very forces which impel segregation in the coarser pores make it impossible for hydrocarbons to traverse the average sedimentary series from bottom to top unless there are open fissures to serve as channels. Nor can the oil be gathered by lateral movement within a bed from distant points to a center of accumulation. Capillarity may only be appealed to as the force responsible for the transfer of oil or gas from one bed of fine-grained rock to a closely adjacent bed of coarser or more open texture, but in probably every oil field other forces have coöperated to concentrate the fluid in small enough compass to make an accumulation of commercial value.

Localization of capillary segregation near surface of earth. Surface tension decreases with increase in temperature until

²³ J. E. Gilpin and M. P. Cram, The fractionation of crude petroleum by capillary diffusion. U. S. Geol. Surv., Bull. 365, p. 33, 1908.

at the critical temperature of the substance it vanishes. The tables prepared by Johnston and Adams²⁴ indicate that with a temperature gradient of 1°C. per 100 feet the total pressure upon a water surface inside pores having diameters of 0.01 microns at a depth of approximately 1 mile would be no greater than the pressure outside the pores due to overlying rock. "Moreover, the surface tensions of all but the lightest hydrocarbons decrease much less rapidly than that of water for each increment of temperature, so that the surface tension of water does not have such great excess over that of oil" at depths of a mile or two as it does in the zone of lower temperature close to the earth's surface. It is therefore probable that capillary segregation of oil and gas must all be effected within two or three miles of the ground surface. At greater depths oil must remain disseminated throughout the shales, if that were its original distribution, unless it had migrated into the sandy strata during the time when the beds concerned were closer to the surface.

Gravitation

Migration of oil is caused directly and simply by the force of gravity only under certain restricted conditions. To permit oil to flow "down hill" in obedience to the attraction of gravity, the oil drops must be in openings not filled with water, and of super-capillary (for crude oil) dimensions. If the openings are tubular, their diameter must be greater than 0.25 mm.; if fissures, they must be more than 0.12 mm. wide. Pores and crevices of greater size than this are probably present in many sedimentary rocks near the surface of the earth, but more commonly they are filled with water. If water is absent from such a coarsely porous rock into which oil has moved, the oil will flow to the lowest portion of the porous stratum and may there collect in commercial quantities. Or if only sufficient water is present partly to fill the open spaces in the bed, the downward passage of the oil will be arrested when it reaches the water-bearing portion of the porous rock.

²⁴ J. Johnston and L. H. Adams, Observations on the Daubree experiment and capillarity in relation to certain geological speculations. Jour. Geol., vol. 22, p. 13. 1914.

Differences in specific gravity

Although the direct influence of gravitation is probably not generally important in causing underground migration of oil or gas, its indirect effect through differences in specific gravity of fluids and gases is unquestionably of prime importance. Most crude oils are quite appreciably lighter than water, especially the heavy salt water which is commonly associated with oil. The excess in specific gravity of water varies from more than 35 per cent, in the case of a very light oil compared with a heavy brine, to less than 5 per cent, if heavy oils be compared with dilute brines. An ordinary crude oil, with a specific gravity of 32° or 33°Baumé, is about 20 per cent lighter than the ordinary salt water with which it is commonly associated. If, then, petroleum and water are associated together in openings of super-capillary size, the difference in specific gravity will result in a tendency for the oil to rise until its upward progress is barred by a rock mass in which the openings are all of capillary size and are filled with water, or until it reaches the surface of the water body which displaces it.

Gravitational sorting of oil and water. The tendency of water thus to drive oil upward in coarsely porous strata is unquestioned; the actual movement of oil due solely to differences in specific gravity is by no means certain. If drops of oil are squeezed from a fountain pen filler against the bottom and sides of a basin filled with water, it may be observed that "most of the drops cling persistently to the vessel and do not rise through the water." The slight difference in weight between the small drop of oil and an equal volume of water is not sufficient in itself to overcome adhesion between the liquid and the adjacent solid, although the area of solid contact is very much less than that which would be operative if the same drop of oil were spread out in the pores of the ordinary sandstone. The drops of oil in the basin of water may be dislodged by stirring the water or by tapping the vessel; or if separate drops are so closely adjacent that cohesion and surface tension unite them into a single large drop, its size may be sufficient to induce

enough lifting force of water displacement to overcome adhesion and inertia, and to float it freely upward. All three of these phenomena are active in the interstices of the rocks. Circulation of ground water may simulate the first; crustal movement, tidal kneading, and earthquake vibrations are the second; and molecular forces are probably identical beneath the surface of the earth to those in the laboratory. But, in the petroliferous rocks, if an oil drop starts to obey the impulse of gravitative displacement, its upward progress is hindered by the friction of the rock surfaces past which it must move. The retarding effect of friction cannot be quantitatively determined from the data now available; it is entirely possible that it may in most instances prevent effective gravitative assortment of oil and water, although this is by no means certain.

Gravitational sorting of gas and water. The displacement of gas bubbles in water is quite another matter. Gas rises through water-saturated sandstone several hundred times as readily as oil. Differences in specific gravity are probably quite competent to concentrate gas above the water body in a porous rock mass. It is probable that soon after the formation of a bubble of gas, as a result of chemical action, change of temperature, or increase in pressure, the bubble would rise through the water in any supercapillary fissure or pore until ascension was stopped by a barrier of water-filled spaces, none of which were of more than capillary dimensions.

Effect of gas migration in transporting oil. But if while being forced upward the bubble of gas touches a droplet of oil clinging to the wall of fissure or pore, it will be surrounded by a thin film of oil, for oil has an extraordinary capacity of spreading along any surface between water and gas.²⁵ Each bubble of gas rising from its place of origin or later moving upward through rock cavities may carry with it a pellicle of oil and thus accomplish gravitational sorting of oil as well as of gas. When the gas bubbles with their films of oil unite in the space to which they are driven by the lifting force of water displacement, the

²⁵ Johnson, R. H., The accumulation of oil and gas in sandstone, *Science*, vol. 35, pp. 458-9, 1912.

oil films will aggregate because of surface tension into drops which will further coalesce into fluid masses separating the gas above from the water below. It is, of course, true that the volume of gas required is many times the volume of oil which it would lift in this way but recognizing the limitations upon the process it nevertheless seems potent to accomplish important results in the migration of petroleum.

Movements of underground water; nature of the movement

Movement of the water beneath the surface of the earth necessarily involves movement of the oil or gas which may be in its path. Underground water, a term used to comprise all aqueous solutions beneath the earth's surface, includes water from many sources and under many various conditions.²⁶ Much of it is seepage, fresh or salt water, which has filtered downward from the surface; some is connate, fresh or salt water buried with sediments; while a small part of it is juvenile, primitive fluids expelled from molten magma or igneous rock by crystallization or heat. Above the water-table—below which most openings in the rocks are filled with liquids—underground water is in more or less constant motion from higher to lower levels. Below the water table, motion is in general slower, and great volumes of water may for motion periods remain practically stagnant. The direction of motion is there determined by pressure and is from places of greater to places of lesser pressure or hydrostatic head. This frequently results in an upward creep and lateral oscillation.

The chief causes of movement of water below the water-table are (a) gravity, expressed in the familiar statement that water tends to seek its own level; (b) changes in temperature which may result from the earth's general heat, from the heat of crustal movements, involving crushing or friction, from chemical reaction, or from igneous intrusion; (c) compacting of rocks by burial, or expansion of rocks following erosional stripping of

²⁶ R. A. Daly, Genetic classification of underground volatile agents, Econ. Geol., vol. 12, pp. 487-504, 1917.

covering; (d) expulsion of juvenile water from igneous masses during crystallization; (e) expansion of gas which may be either of abyssal origin or newly formed by pressure upon organic materials at moderate depths.

Washburne infers

a small, but locally active, very slow; outward creep of the rock fluids (liquid or gas or both) due to pressure from below. The principal reason for the inference is based on plotting the distribution of pressures in the sands of different fields of the United States and of Canada for which data are available. The data are not sufficiently complete to warrant final conclusions, but there are many instances in which the downward increase of pressure between sands, and the increase above the surface pressure, exceed the corresponding hydrostatic head. . . . It seems significant that excess pressures are most common in the more fractured regions, such as Baku and the Gulf Coast, where the deep communication appears to be more open than elsewhere. Other arguments for this ascent are found in the excess temperatures in oil fields, in the distribution of oils and gases of filtered and unfiltered types, in the excess of chlorine in the associated water, and in the abundance of helium in the deep wells of Kansas.²⁷

Effect of movement upon accumulation of oil

The chief contribution of ground water circulation to the underground accumulation of oil and gas in commercial quantities is probably made as a conditioning rather than as a causal agent. Movement of subterranean fluids may assist in overcoming the adhesion and inertia of oil globules, which might otherwise prevent differences in specific gravity from accomplishing gravitative sorting. Johnson²⁸ states, for example, that differences in specific gravity, and in capillary action seem remarkably impotent when everything is at rest, but that assisted by a little movement these differences bring about very important results. If oil-soaked sand is placed in the middle of a horizontal tube and water-soaked sand is placed at either end, the tube may remain at rest a very long time without any

²⁷ Washburne, loc. cit., p. 956.

²⁸ R. H. Johnson, Discussion of Capillary concentration of gas and oil, Am. Inst. Min. Eng., Trans., vol. 50, pp. 842-843, 1915.

appreciable change in the relative position of oil and water. But with a little motion that oil will gradually be distributed above the water along the upper side of the tube. It does not appear to be necessary to have very extensive movement, but some degree of movement is essential.

Or, again, the slow circulation of ground water may permit surface tension phenomena to play a part which would otherwise be denied them. If a body of gas has been segregated above the water in porous sands, circulation or migration of the water may bring globules of oil to the surface of contact between gas and water. If so, these will be held on the surface of the water by its tension. The oil will first spread as a film along the gas-water surface and any oil which is brought in contact with this film must join it. In this way oil may accumulate above water in any subterranean reservoir in spite of the slight difference in specific gravity between the two fluids. "Any movement of the water in the sand, which would in time bring the various parts of the water in contact with its upper surface, would carry bodies of oil of all sizes to the water-gas surface, where surface tension would retain them permanently."

Rich believes that the

principal cause of the migration of oil and gas is the movement of underground water which carries with it minute globules of oil and bubbles of gas, possibly as fast as they are formed. Accumulation results from the selective segregation of oil and gas, which, on account of their buoyancy, always tend to work their way upward as they are carried along and are caught and retained in anticlinal or other suitable traps.²⁹

Gas expansion

Destructive distillation of organic matter, animal or vegetable, under conditions such as those commonly occurring within the body of the earth where free access of air is precluded, produces hydrocarbon gases as well as liquid hydrocarbons. The process

²⁹ John L. Rich, Moving underground water as a primary cause of the migration and accumulation of oil and gas, *Econ. Geol.*, vol. 16, pp. 347-371, 1921.

is a biochemical one, effected largely by the action of anaerobic bacteria before the deposits are deeply buried or the formation firmly consolidated. But later, if the same beds are covered with thick accumulations of younger sediments, gas may be formed as a result of the action of heat upon the entombed organic matter, liquid or solid. This thermochemical process³⁰ is accompanied by polymerization of the oil and may be furthered by the increase in pressure resulting from burial. The two kinds of action are mutually complementary; the first mentioned dwindles to nothingness as the second increases in effectiveness; the first is long continued, but the second knows no time limit. Consequently, new gases are produced long after the petroliferous beds are more or less completely sealed by water-saturated "cover rocks."

To these organic gases, there may possibly be added in some localities a modicum of abysmal gas, inorganic in origin, slowly ascending from the deeper interior. The presence of argon and helium among the gases from the deeper sands of Kansas may be thus explained. But regardless of any possible inorganic contributions, these lighter hydrocarbons may be formed under all conditions of temperature and pressure, including those far above their critical temperatures and pressures, so that they may be in that state of matter where the true distinction between gas and liquid disappears.

Gas expansion, if permitted by local physical conditions, will drive fluids, petroleum or water, out of the larger openings in the rocks more readily than from the smaller ones where viscosity and capillarity tend to retain liquids. Relief of pressure at any point or along any plane may result in the migration of oil and water in front of the expanding gas. The result would frequently be scattering of oil rather than concentration, but upward movement would be favored, for relief of pressure would more commonly come from that direction. Hence, here

³⁰ R. H. Johnson, The rôle and fate of the connate water in oil and gas sands. *Am. Inst. Min. Eng., Bull. No. 98*, pp. 221-226, 1915; *Trans.*, vol. 51, pp. 587-610, 1916.

is another cause tending toward the elevating of oil, if not toward the top of any subterranean reservoir, at least toward the surface of the earth.

Mills has recently³¹ called attention to the importance of the escape of gas with entrained oil through fissures as a factor in the migration and accumulation of oil in many faulted areas. Both experimental and field data seem to indicate that "oil is propelled more effectively than water by the propulsive force of absorbed gas. Immediately upon the release of pressure, the absorbed gas expands and propels the oil from within. The comparatively high absorption capacity of oil and its tendency to remain entangled with the flowing and expanding gas appears to be largely responsible for this effective propulsion." Such migration of gas and oil in fault or other fissures "has been upward either to the surface or from one bed to another. Fissuring has also facilitated the lateral migration of oil and gas through porous beds toward these points of escape."

Earth movements; folding and faulting

The accumulation of strain within the earth's crust may exceed the resisting strength of the strata and necessitate adjustments by folding or faulting movement. In so far as these adjustments involve decrease or increase of reservoir volume, they may result directly in the transfer of oil or gas from place to place. If *similar folds*³² are formed, the beds will be compressed and thinned on the limbs of anticlines and synclines, but thickened and expanded on the crests and in the troughs of the folds. The result will be a tendency toward the migration of interstitial fluids from the place of compression to the places of lesser pressure—the crest of an anticline or the bottom of a syncline. The balance between folding movements competent to cause such migration and those which would cause regional dynamic alteration sufficiently complete to volatilize all the

³¹ R. Van A. Mills, Natural Gas as a factor in oil migration and accumulation in the vicinity of faults, Bull. Am. Assoc. Petroleum Geologists, vol. 7, pp. 14-24, 1923.

³² C. K. Leith, Structural Geology, Henry Holt & Co., New York, 1913, p. 106.

lighter distillates from the petroliferous substances is, however, so delicate that it is doubtful if folding movements have contributed largely to the accumulation of oil in economic amounts.

Indirectly, folding and faulting of the earth's crust may have materially assisted in the migration and segregation of oil by providing that element of motion which seems essential to the effective operation of such motive forces as capillary action and gravitative assortment. The frequency of earthquake vibrations is suggestive of the repetition of jarring shocks which may have operated to overcome adhesion and inertia which were militating against gravitative assortment of oil and water.

Similarly, the development of fault fissures may afford channels for the escape of compressed gasses, and thus be the indirect cause of migration and accumulation of oil impelled by expanding gas, as noted in the preceding section.

Body tides

Regularly recurrent oscillatory movements within the body of the earth are caused by the attraction of sun and moon. Experiments undertaken to determine the rigidity of the earth by tidal observations indicate³³ that the water tides are of much less amplitude than they would be if the earth were absolutely rigid, and that in fact three- or four-tenths of the tidal strain is compensated by tides within the earth's body. These movements may be compared to the kneading to which a baker subjects dough. They would in general result in an upward migration of earth fluids because as the liquids are squeezed out they would move, if possible, in the direction of least pressure. This kneading of the earth, like the less regular folding and faulting movements, has probably been an important contributing cause of oil and gas migration, notably assisting the operation of other forces.

THE PROBABLE HISTORY OF MOST OIL AND GAS ACCUMULATIONS

Having thus reviewed the possible causes of the migration of oil and gas, the probable history of the majority of the great

³³ A. A. Michelson, Preliminary results of measurements of the rigidity of the earth, Journ. Geol., vol. 22, pp. 97-130, 1914.

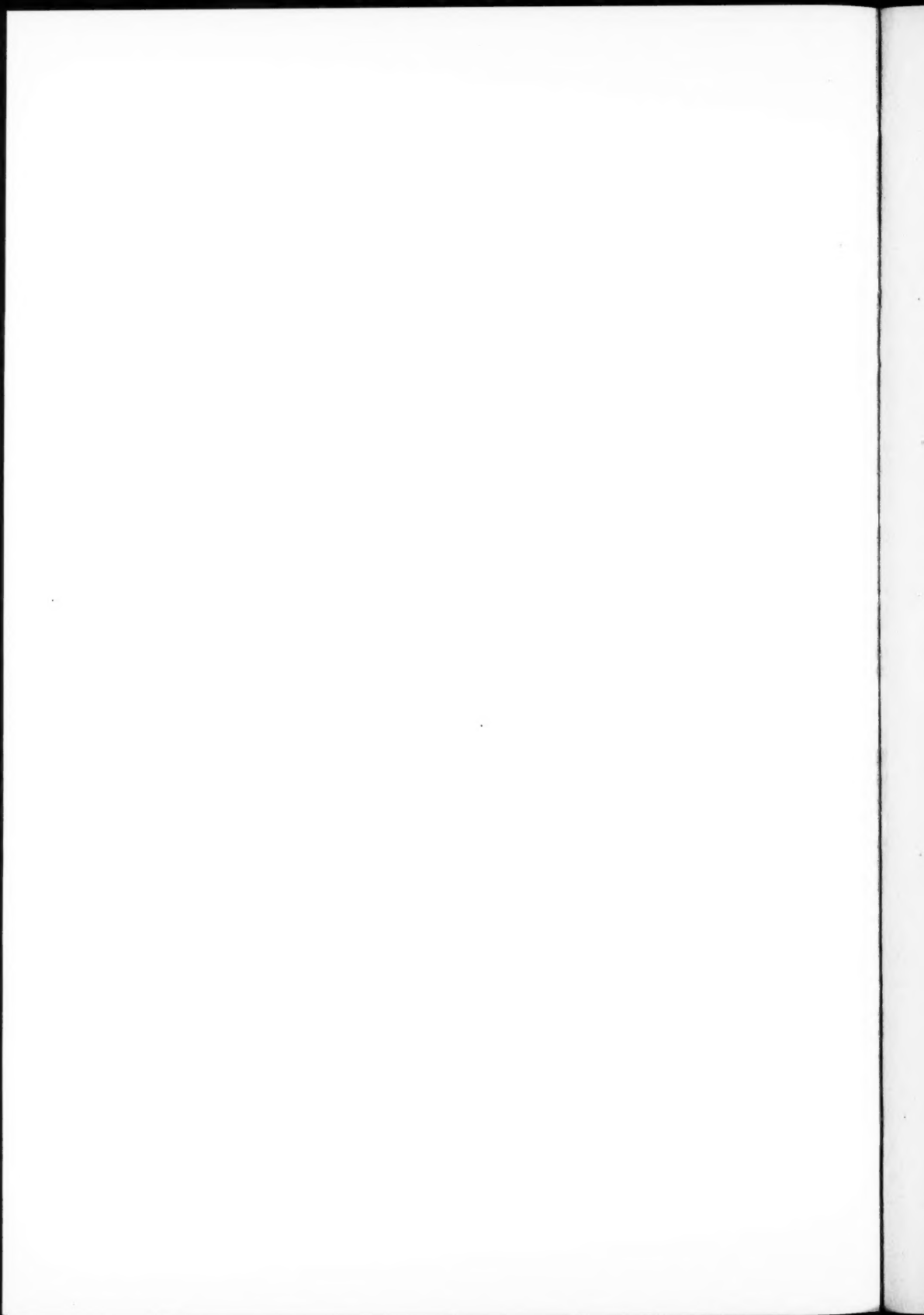
commercial accumulations of these substances may now be sketched. Variations in the relative importance of the different factors involved may of course be expected because of the fact that each oil or gas field is actually unique in its composite features, but the general story needs only slight changes in its major outlines to make it apply to most fields.

Distillation, at first dominantly biochemical and later dominantly thermochemical, begins with the entombment of organic matter in muds, clays and silts. With continued accumulation of interstratified sandy and muddy layers, the oils and gases thus formed are squeezed out of the finer into the coarser sediments. Differential capillary action draws water into the finer openings while the volatile hydrocarbons move into the larger ones. Thus, transverse migration from the shale birth-place of petroleum to the reservoir sands and sandstones takes place. Circulation of subterranean fluids and movements of the earth's body all contribute to this movement from one layer to an adjacent one; whenever oil or gas enters coarsely porous portions of the earth's interior, completely enclosed by water-saturated fine-grained rocks, there it must remain. Transverse migration is never complete; the shales invariably retain more or less of the petroleum which originates therein; it is more nearly complete where there are several sandy layers interbedded at frequent intervals within the shale series than where the same amount of sand is concentrated into a single formation.

Oil and gas which enters coarsely porous strata, sandstones or limestones, will move more or less completely to the pores above those occupied by water within the reservoir. If the rocks are saturated with water, differences in specific gravity, molecular forces, ground water movement, etc., will lift the hydrocarbons to the top of the reservoir and segregate them beneath fine-grained strata or portions of strata. If the reservoir roof is sufficiently inclined, the upward force will be resolved into lateral movement which in most cases will be parallel to the bedding of the rocks. This obliquely upward migration will be stopped where the oil or gas is trapped by changes in the pitch of the reservoir roof. Hence, a knowledge of the shape of the

reservoir is a prime essential to wise exploitation of petroleum accumulation. If, on the other hand, the reservoir is only partly filled with water, oil should be accumulated above the water surface, unless the pores are of capillary dimensions (for oil) in which case it will be broadly disseminated through that portion of the reservoir which is devoid of water. Hence, knowledge of the water conditions and the porosity of the reservoir rocks are likewise of first importance to the petroleum engineer. Lateral migration does not necessarily require an upward component, especially if it is due to gas expansion, but, because of the general prevalence of water in a more or less static condition within the strata from which oil and gas are obtained, it probably has nearly everywhere proceeded in an obliquely upward direction. Its results in concentrating oil and gas in certain parts of the reservoirs will depend chiefly upon their shape.

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